USING BIOMECHANICAL ANALYSIS AND USER FEEDBACK TO EVALUATE OPTIMAL DESIGN SPECIFICATIONS IN LIFT ASSIST DEVICES

by

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STATEMENT OF THESIS APPROVAL

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ABSTRACT

Lifting heavy loads is a major concern for workers and employers as it may contribute to low back pain (LBP). Although a workstation may be ergonomically abated so as to reduce lifting, it is not reasonable to completely eliminate all lifting from some jobs. For this reason, a great deal of work has been done to study the biomechanics of different lifting techniques. More recently, in an effort to reduce the risk involved with lifting, new technology is emerging that aids with human-powered lifting. A Lift Assist Device (LAD) is a mechanical aid that supports some of the forces or torques during lifting, by transferring them to an area with a lower risk of injury.

The main objective of this study was to investigate the effectiveness of LAD designs, and identify key features to be incorporated into future LAD designs.

Ten healthy male participants tested 36 combinations of four LAD conditions (three different designs and nonassisted), at three different speeds (slow, medium, fast), and with three twisting conditions (left, forward, right). The LAD designs included three unique methods for generating torque, two prototypes, and one commercially available device.

Many statistically significant ($p<0.05$) differences between devices and between lifting postures were identified. These differences were examined to show strengths and weaknesses in the effect of each LAD. This information may be useful when choosing a specific type of LAD for a particular job and when considering future designs for LADs.

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LIST OF ABBREVIATIONS

LAD	Lift Assist Device
LBP	Low Back Pain
EMG	Electromyography
*TA	Torso Angle
*LHA	Left Hip Angle
*RHA	Right Hip Angle
*TW	Twist
*SE	Shoulder Elevation
*MA	Moment Arm
*RES	Right Erector Spinae
*RRA	Right Rectus Abdominus
*REO	Right External Oblique
*LES	Left Erector Spinae
*LRA	Left Rectus Abdominus
*LEO	Left External Oblique
* indicates that the abbreviation may include one of the following abbreviations: M = mean, P = peak, C = cumulative	

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CHAPTER 1

INTRODUCTION

Background

Low back pain (LBP) is a widespread problem with significant economic implications. Nearly all adults know someone who has had a debilitating episode of LBP or have experienced it themselves [1]. Although LBP continues to be a topic with strong research interest, a great deal remains to be studied. The causes of LBP remain somewhat mysterious because they are usually multifactorial in nature, and develop over many years. The etiology of LBP has not been effectively defined, not because it is too complex or an insurmountable challenge, but because diagnoses and treatment strategies remain unclear [1]. However, through extensive research, an association has been established between lifting heavy objects or lifting objects frequently and increased LBP [2].

Lift Assist Devices (LADs) may function as an aide in the prevention and rehabilitation of low back injuries. Although some research has been done to quantify the effectiveness of LADs, little work has been done to compare LAD devices. Additional research is needed to describe the effectiveness of LADs to act as a rehabilitation device after a back injury. LADs may also help prevent overexertion or re-injury while lifting. A goal of this study is to test and compare three LAD designs.

A Lift Assist Device is a mechanical aid that transfers some of the forces or torques which are involved with lifting to an area with a lower risk of injury. Some recent advances in this technology have been made, leading to design improvements as well as new device designs. An example of a new device design is the PLAD (Personal Lift Assist Device), as shown in Figure 1, which was designed to assist human muscles through the use of elastic elements [3].

The PLAD was designed, developed, and tested in the Biomechanics and Ergonomics Lab at Queen's University, Canada, and is now being marketed for industrial use.

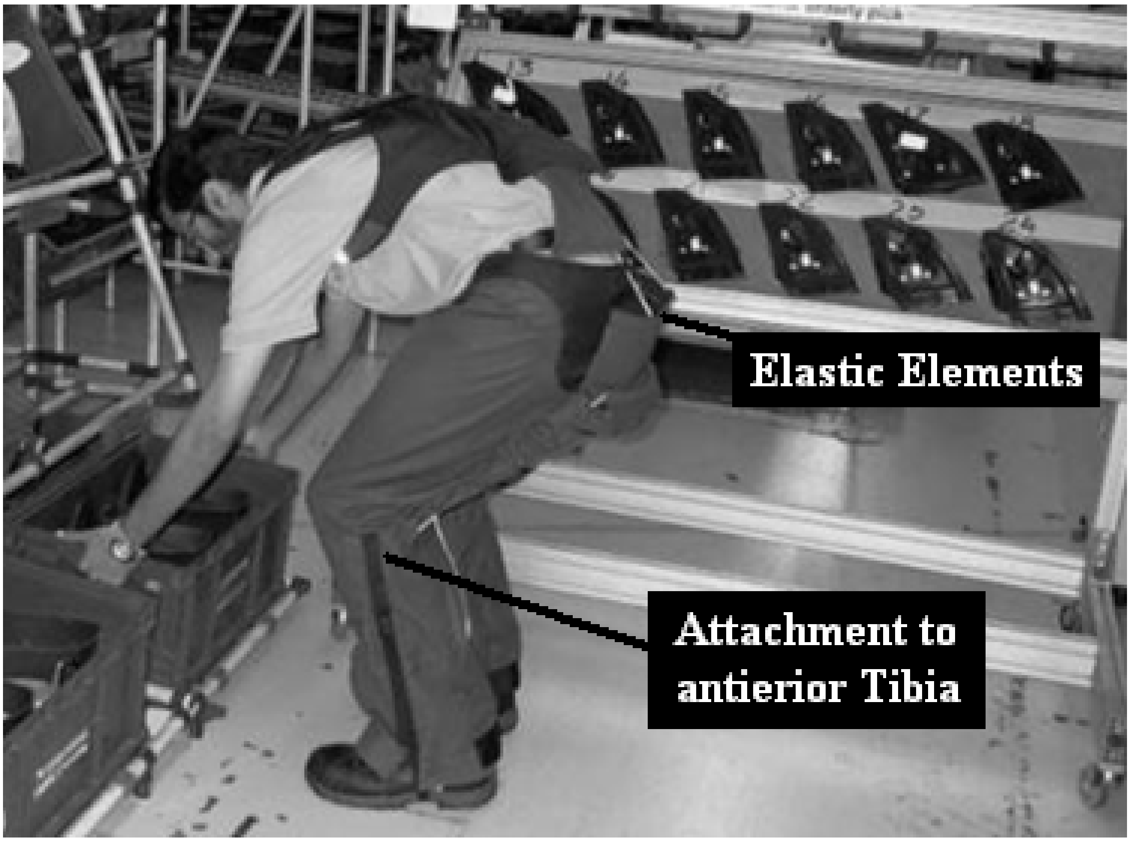


Figure 1 The PLAD Worn During Work in an Industrial Assembly Plant

Another example of a new device on the market is the Springzback™ as shown in Figure 2, which takes a different approach by attaching to the anterior side of the body using a custom waist belt and straps. This device is also commercially available for purchase and claims to have benefits, especially for static trunk flexion.

As new devices are invented, developed, and distributed, the need to learn about and experiment with these devices is growing. Such devices inspire the creation of other prototypes, and with the analysis of previous models, improvements can be made.

Scope of the Problem

Since Lift Assist Devices are a relatively new technology, there is a great deal of information that needs to be acquired to prove their effectiveness, and to make design changes for optimal performance. Studies have been performed which use biomechanical analysis techniques to quantify the functionality of some specific LADs [4], and these

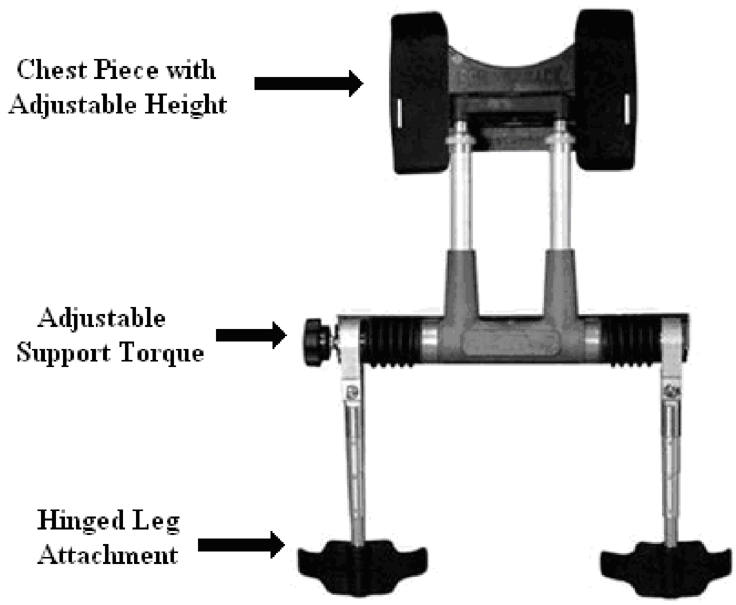


Figure 2 Springzback

studies have been instrumental in the development of new designs and design improvements. Much of the work currently being carried out evaluates the effectiveness of reducing strain and fatigue on specific muscles, namely the Erector Spinae muscles [3]. The results from these studies indicate the potential that LADs have in reducing the probability of a musculoskeletal disorder involving low back pain; however, they generally do not thoroughly explore the other areas of the body that may be affected by LAD use. More work is still needed to evaluate the effectiveness of these designs.

Hypotheses

The main hypothesis of this study is that particular LAD designs have a unique effect on trunk muscle activation, and lifting posture and these effects are modified by required speed of lift and the location of the load destination. The null hypothesis is defined as:

$$H_0: \mu_1 = \mu_2 = \mu_3 = \mu_4$$

where μ is the study parameter mean for the lifting scenarios with no device (μ_1), the Springzback Device (μ_2), the Bending Device (μ_3), and the Torsion Spring Device (μ_4).

It is suspected that the use of LADs imposes increased requirements on other parts of the body. Furthermore, it is suspected that some designs have specific attributes that contribute to a more optimal LAD. The goal of this study is to identify the characteristics of LADs that may be useful to develop a more optimal design, and to quantitatively analyze these characteristics. The information acquired may be used for making suggestions to improve future designs and lead to improved performance with minimal undesired side effects.

CHAPTER 2

METHODS

Lift Assist Device Designs

Three types of LADs were chosen for evaluation. Their wide range of differences was expected to provide useful information about the effect of these design differences on lifting biomechanics. Each design uses a unique method to provide torque about the hip joint.

Torsion Spring Device

Figure 3 shows a LAD that uses a torsion spring to provide torque. The spring is attached to the LAD near the hips and preload is adjusted with a torsion knob. As the user bends the torso, energy is stored in the springs and provides a resisting torque to support the upper body, reducing the back compressive force in the spine. This design includes an adjustable waist support and padded adjustable backpack straps. The rigid extension behind the user's head with adjustable webbing straps attaches to the backpack straps. This feature is intended to prevent the weight of the device from resting on the shoulders, which would increase spinal compression. The leg extensions, torso extensions, and device width on both the left and right sides are all adjustable in length. The leg extensions prevent movement other than flexion or extension of the legs relative to the torso. This device weighs 13 pounds.

Figure 3 Torsion Spring LAD

Bending Device

Another unique LAD design is shown in Figure 4. As a user's body bends, energy is stored in fiberglass members, and the energy is released as the user straightens the body. The device resists bending, but assists while straightening the body during lifting. It also helps support the body when a static, flexed torso posture is present. The sliders placed on both of the leg attachments allow the user a more comfortable range of motion that may be helpful when walking. The upper segment attaches to the user's torso much like a backpack. The lower two attachments connect to the user's thighs with quick-release straps. The device also resists overextension as a safety feature. Although this device is designed to provide the user with a full range of motion, it lacks characteristics

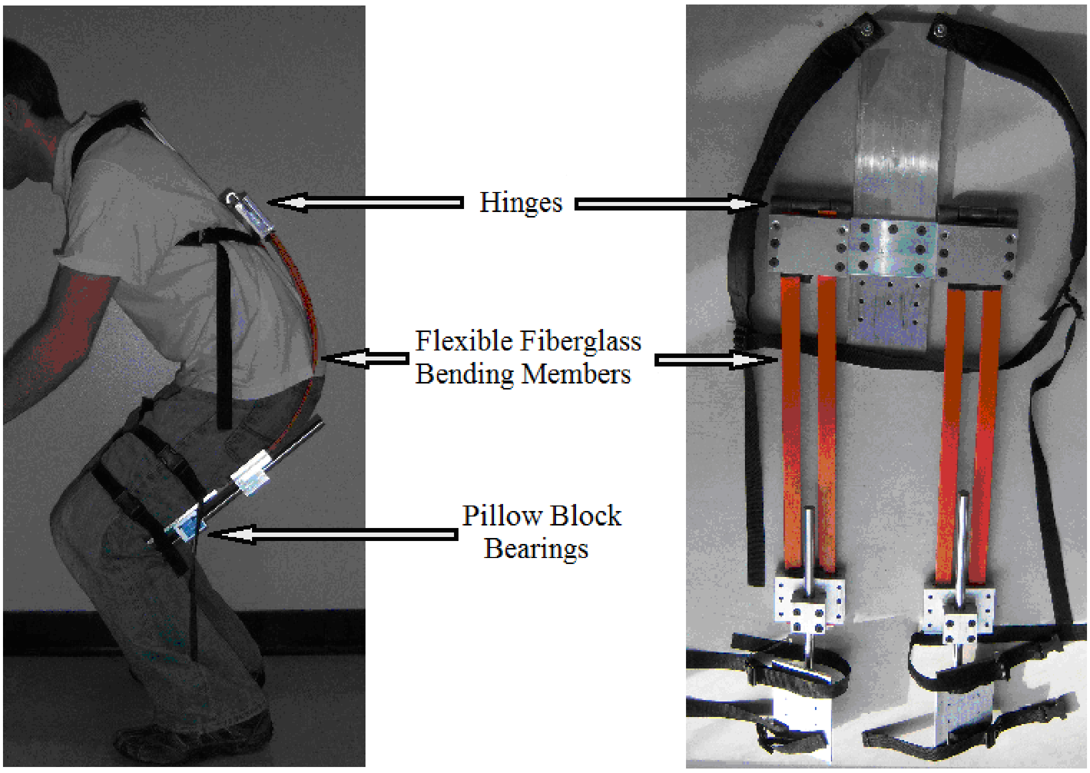


Figure 4 Bending LAD

that may be considered important for use such as padding and being light weight. This device weighs 17.5 pounds.

Springzback Device

The Springzback™ (Figure 5) is a commercially available device that provides relief to the back while bending. A special belt is worn by the user and the device clips to the belt on the anterior side of the pelvis. A unique attribute about this LAD is that it attaches to the front of the body and provides the support from the front as opposed to the back. The device utilizes an adjustable fluid compression spring to provide resistance when bending the torso. Similar to other designs, this resistance may reduce some of the force in the muscles while lifting, but likely has the greatest benefits during static

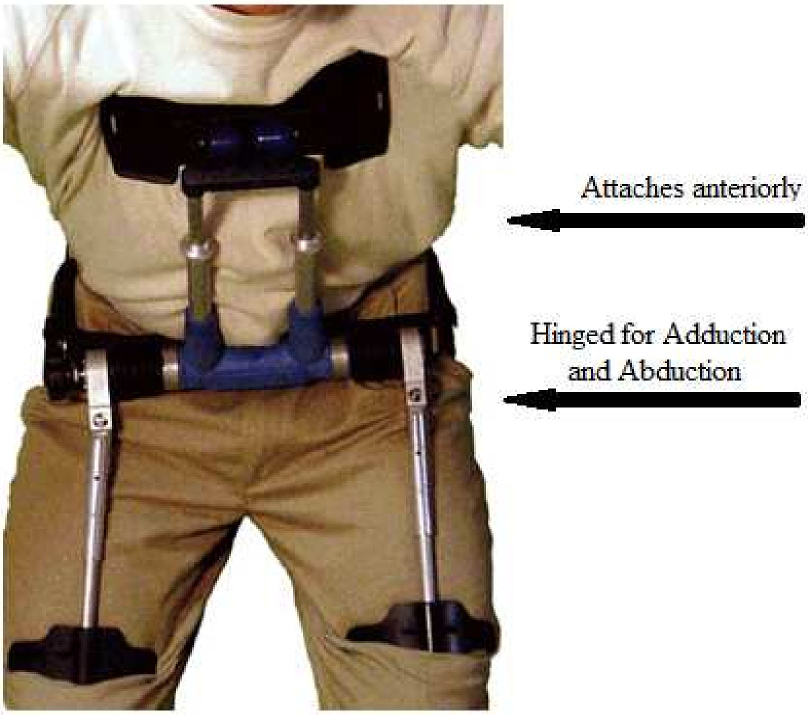


Figure 5 Commercial Assisting Device "Springzback"

postures with a flexed torso. Like the other two lift assist devices described above, this mechanism allows each leg to move independent of the other. But unlike the other two devices, this design includes a hinge which allows for abduction and adduction of the legs (or moving the legs from side to side). This is the lightest of the three devices, weighing 4.5 pounds, including the belt.

Equipment

Two force plates (model OR6-5-1000 & OR6-7-1000, AMTI, Watertown, MA) were incorporated to measure ground reaction forces and moments for each foot. These data are used to calculate forces and moments throughout the body using inverse dynamics. The analog data were collected at 1000 Hz.

Surface electrodes were placed on each participant to measure the electromyographic (EMG) signal of each of six muscles. An adhesive electrode pair was placed on both the left and right side for the erector spinae muscles, the rectus abdominus muscles, and the external oblique muscles according to the positioning shown in Figure 6. One extra electrode was attached on the participant's Right Iliac Crest as a common ground across all EMG signals. Although surface EMG includes the risk of picking up muscle activation signals from nearby muscles, it was chosen as a less invasive option when compared to needle electrodes. Marker positions were collected with a Natural Point Infrared Eighteen Camera System using Optitrack Cameras and ARENA software (NaturalPoint, Corvallis, OR). Reflective markers were placed on each participant's body in the following locations: calcaneus, medial malleolus, lateral malleolus, hallux, tibia, lateral condyle of the femur, medial condyle of the femur, greater trochanter, anterior superior iliac spine (ASIS), joint between the L5 and S1 vertebrae, acromion, and C7

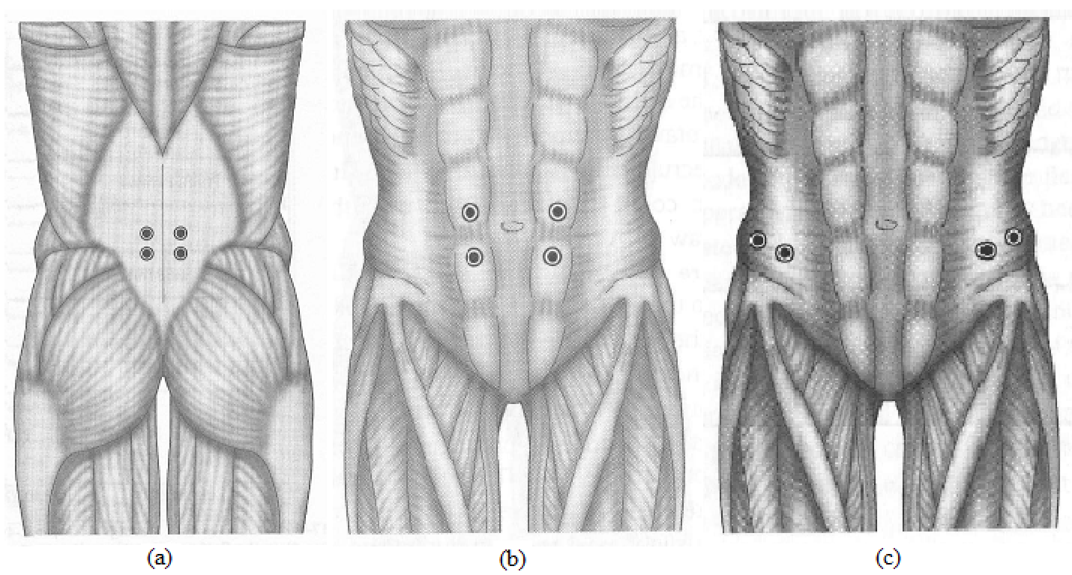


Figure 6 Surface EMG Electrode Placement for Erector Spinae (a), Rectus Abdominus (b), and External Oblique (c) Muscles

vertebra. Reflective markers were placed unilaterally on each of these anatomical landmarks except the two markers centrally placed on the spine, as shown in Figure 7. Figure 7 also displays the other marker locations.

A total of 22 markers were tracked on the participant's body during each trial, but an additional four markers were placed on the 25 lb. load to identify of the position and orientation of the load in the global coordinate system.

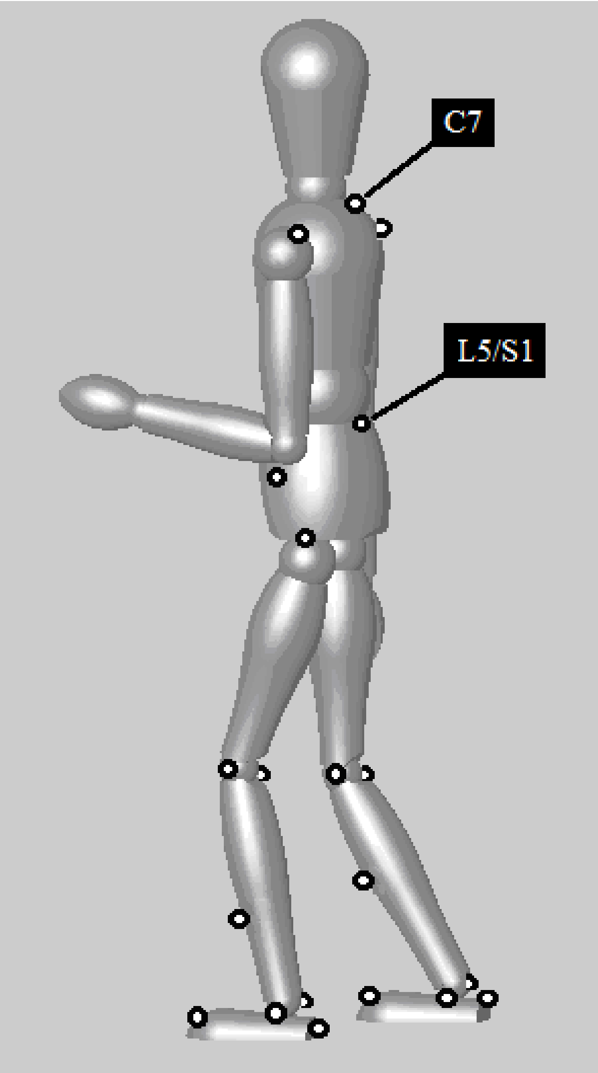


Figure 7 Reflective Marker Locations

Subjects

Ten (10) healthy males agreed to participate in this lifting study (age = 31.8 ± 9.14 y, height = 1.76 ± 0.08 m, weight = 75.43 ± 8.3 kg). Table 1 contains a summary of physical information of participants. Although it would be informative to use participants with previous back injuries, and compare them to a healthy sample population, no participants who had back injuries or who currently had LBP were allowed to participate in the study.

Informed consent was given prior to participating in the study in accordance with the Institutional Review Board (IRB) of the University of Utah. Each participant signed the consent form and was given an extra copy to keep for his personal records. The average participant body mass index (BMI) indicated a population of normal weight (24.37 ± 2.03), as shown in Table 1, although this is near to the overweight category for BMI.

Procedures

Each participant was asked to review the IRB approved consent form, and was given a thorough explanation of the procedures of the study by a member of the research staff. Physical measurements were taken, and the reflective markers were attached to the participant’s bony landmarks as described above. Next, EMG electrodes were affixed

Table 1 Summary of Participants' Physical Information

Age (SD)	Height (SD) in meters	Weight (SD) in kg	BMI (SD)
31.8 (9.14)	1.76 (0.08)	75.43 (8.3)	24.37 (2.03)

according to surface EMG placement suggestions given in [5]. Thirteen electrodes were placed with two per muscle on the left and right Erector Spinae, Rectus Abdominus, and External Oblique muscles, and one electrode was placed on the right Iliac Crest to serve as a reference. Although the electrodes are adhesive, it was found that they frequently needed to be adjusted or replaced because of movement. A layer of semi-elastic fabric was then placed on top of the electrodes, stretching around the lower torso to secure the electrodes in place, and to prevent moving clothing from contacting the electrodes.

With markers and electrodes in place, the participant was brought to stand in the lifting area so that each foot resided on a separate force plate. The 25 lb. load was placed just off of the force plates in front of the participant so that the person could comfortably reach and lift the load, as shown in Figure 8. A small table was constructed to provide a 30 inch tall load destination which could be moved so that the destination would be positioned on the left, right, or in front of the person, which allowed for the observation of a lift with twist in either direction. In this study, the destination for a twisting lift was positioned 90 degrees to the right or left of the person’s forward faced direction.

A metronome was used to dictate to the participant the desired duration of lift. Three different durations were observed in this study: slow (3 seconds), medium (2 seconds), and fast (1 second). These times were chosen to represent two extremes in lifting speed (slow, and fast), as well as an approximate neutral speed (medium). The person was given a chance to perform practice lifts before data were collected, and a test run was performed with each participant before beginning the trials to ensure that all equipment was functioning properly. A photo of the setup is shown in Figure 9.

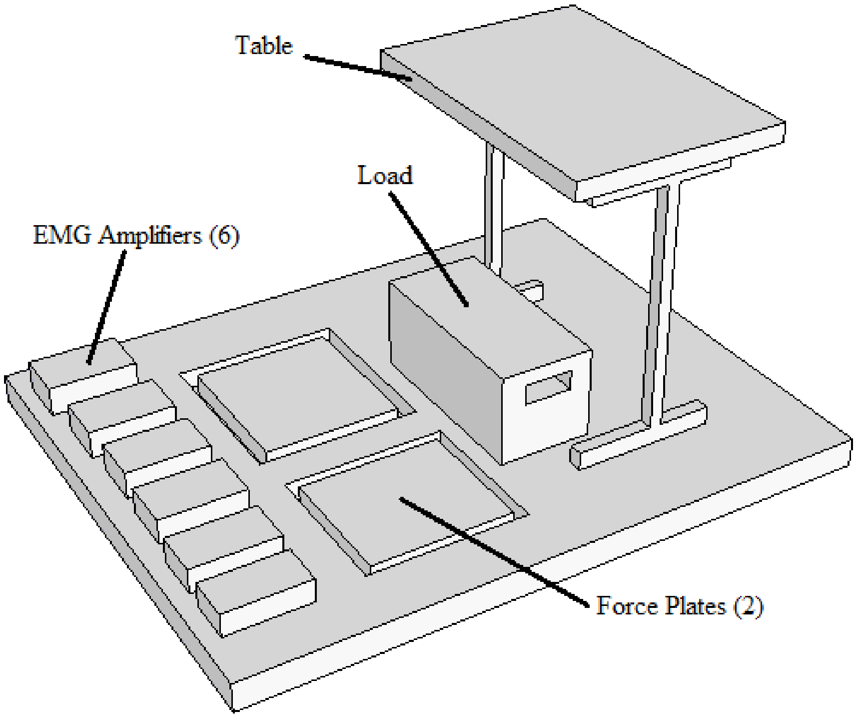


Figure 8 Lifting Platform Arrangement

Figure 9 Experimental Setup

With the participant and equipment ready, the person conducting the study arranged for each lifting trial to be carried out for the desired speed, target location, and LAD usage. These scenarios were randomly pre-assigned to each participant, to prevent any systematic bias of results.

All three LADs were used for each lifting trial, were assigned in a randomized order, and lifting trials with no LAD to serve as a control were also performed. Three target destination scenarios and three speeds for a total of 36 trials were performed by each participant. Each lifting trial was performed repeatedly for 30 seconds to allow the participant to work with a rhythm and to ensure that clear data for at least one lift cycle were obtained. Although a true cycle would require that a person return to the same position as in the beginning of a cycle, this study only focuses on the lifting, and not lowering action. For the purposes of this paper, a cycle begins when the load is lifted from the floor, and ends when it is set onto the target destination.

After all trials were completed, each participant completed a questionnaire regarding the participant's experience with a device. An individual questionnaire was filled out for each device. This survey contains a series of nine initial questions that are answered using a color-coded, five-response scale ranging from "strongly agree" to "strongly disagree." Two yes/no questions are also included. These two types of questions comprise the quantifiable portion of the questionnaire, and the three remaining questions are open-ended so the participant is free to add a response that the previous questions may not have addressed.

Data Analysis

The motion capture data were trajectorized and exported to a C3D file using the Arena software. Vicon Motus data acquisition system (Vicon Motion Systems, Centennial, CO), Custom software (LabView, National Instruments), and Microsoft Excel were used for all of the subsequent data analyses.

Joint centers were calculated for the ankles and knees by finding the midpoint between the lateral and medial malleoli, and the lateral and medial femoral condyles, respectively. Joint centers for the hips were calculated using the equation below [6],

$$\begin{aligned}\mathbf{p}_{\text{Hip}} = \; & \mathbf{p}_{\text{Sacrum}} \\ & + \; (0.598)(\text{ASIS breadth})\mathbf{u}_{\text{Pelvis}} \\ & +/- \; (0.344)(\text{ASIS breadth})\mathbf{v}_{\text{Pelvis}} \\ & - \; (0.290)(\text{ASIS breadth})\mathbf{w}_{\text{Pelvis}}\end{aligned} \qquad \textbf{Equation 1}$$

where P_{hip} is the position of one hip joint center, P_{sacrum} is the position of the sacral marker, and u_{Pelvis}, v_{Pelvis}, and w_{Pelvis} represent an alternate reference system for the pelvis.

Joint center locations were then used to calculate torso angle relative to horizontal, hip angles (left and right), angle of twist, and angle of sideways bend. The horizontal distance from the L5/S1 marker to the load centroid was also calculated. These measurements were chosen as a way of recognizing lifting posture technique, and quantifying them for comparison between devices, lifting speeds, and target locations.

The torso angle was taken relative to horizontal so that the angle increases as the person moves to the standing upright position. Since this study includes data in three dimensions, instead of just in the sagittal plane, the hip angles were calculated independently. Each one was calculated by finding the angle between three points: the knee joint center, the hip joint, and the acromion. It was necessary to acquire both the torso angle and the hip angle since the effect of LAD on each was an independent variable of interest.

The angle of twist was chosen as an important observable parameter since a relationship has been established between twisting and back problems [7]. An explanation of the trouble involved with twisting while lifting is given in the following comment from Dean Moyer, author of *Rebuild Your Back.*

> In physics, stress is classified according to type such as tensile strength (stretching the object), torsional strength (twisting the object), shear strength (lateral tearing of the object), and compressive strength (load bearing ability).
>
> Of course, the normal intervertebral disc is designed to withstand all of these stress factors, but the two that appear to have the most impact on herniation are twisting and compressive loading. [7]

The angle was calculated by setting up a new reference system, as shown in Figure 10. To set up the reference system, two virtual markers were created: one at the midpoint between the hip joints, and one at the midpoint between the shoulder markers. A frontal plane was created using the two hip joint markers and the virtual point between the shoulders. **U** is in the direction from the upper virtual point to the lower virtual point, **W** is normal to the plane, and **V** is set in the plane and normal to **W**. The angle of twist is calculated using the vector from the upper virtual marker to the right shoulder with the following equation

$$\tan \theta = w/-v \qquad \textbf{Equation 2}$$

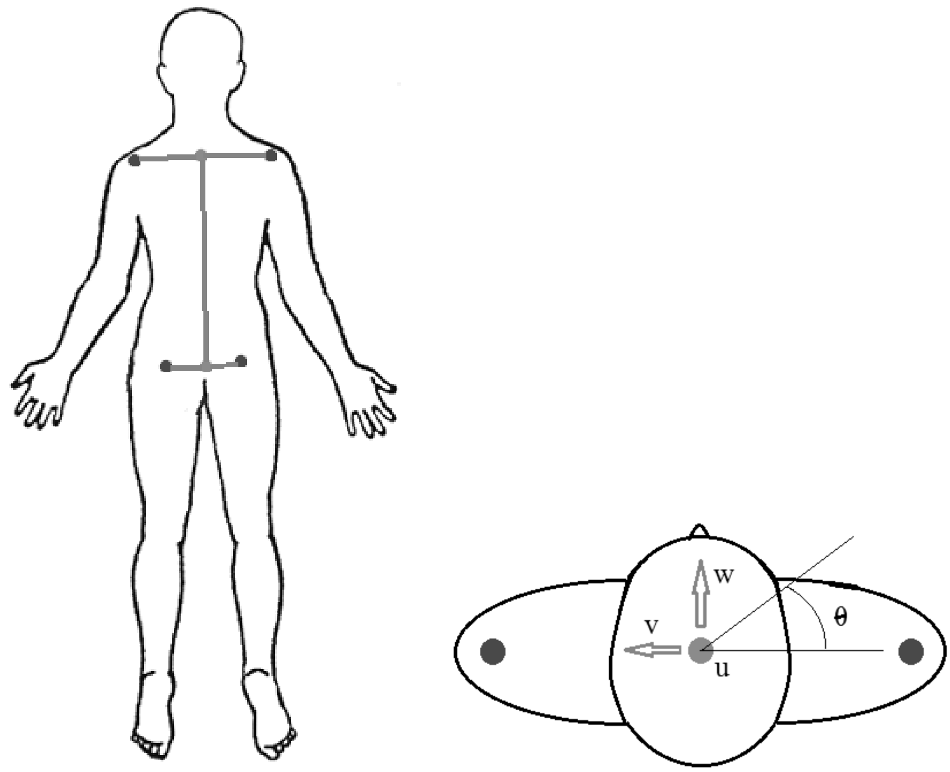


Figure 10 Twist Angle Reference System (u is out of the page)

where **w** is the component of the vector in the person's forward facing direction, **v** is the component of the vector in the direction to the person's left, and theta is the twist angle with the right shoulder forward indicating a positive angle, as shown in Figure 10. This method of twist angle calculation was used in order to account for twist independent of torso angle.

The shoulder elevation angle was calculated using the same reference frame as explained above. To calculate this angle the vector is directed from the upper virtual marker to the right shoulder with the following equation

$$\tan \alpha = u/-v \qquad \textbf{Equation 3}$$

where **u** is the component of the vector in the direction coming out of the top of the head of the person, **v** is the component of the vector towards the person's left, and alpha is the twist angle with the right shoulder elevated indicating a positive angle, as indicated in Figure 11.

This value was chosen because an increase in angle represents a deviation from neutral posture, and may indicate modified behavior using a particular LAD.

The moment arm of the load was also calculated as the horizontal distance from the L5/S1 to the load centroid. This measurement was included because this moment arm has a proportional relationship with the loading of the spine. An increase in moment arm causes an increase in spinal compression.

As mentioned earlier, EMG data were collected for major trunk muscles. Six channels were collected including the Right Erector Spinae muscle, the Right Rectus Abdominus muscle, the Right External Oblique muscle, the Left Erector Spinae muscle, the Left Rectus Abdominus muscle, and the Left External Oblique muscle. The analog EMG data were first pre-amplified with a 1K gain. Vicon Motus Data acquisition system (Vicon Motion Systems, Centennial, CO) was used to process the pre-amplified EMG data. In this process, the signals were first filtered using a digital bandpass filter. The signals were then demeaned (which removes any offsets based on the mean signal), rectified (which processes the signals through an absolute value function), and finally a smoothing envelope was applied to the signals to provide a smooth positive signal indicative of the level of muscle activation.

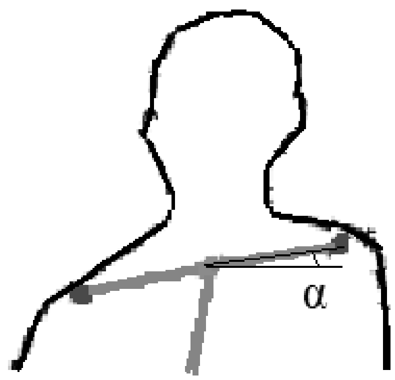


Figure 11 Shoulder Elevation

The processed EMG measurement was normalized across subjects using the EMG levels obtained from the control lift of each subject, i.e. a forward medium-speed lift with no device. For each muscle, the processed EMG signal for four repetitions of this type of lift was measured. The peak EMG signals at similar points during the lift were averaged to create a reference point at 100% of the muscle activation under control conditions. For other trials where the independent variables are changed, the processed EMG levels are normalized according to this reference. This method of EMG normalization is a common technique used in cyclic motions such as gait analysis [5]. Since the lifting performed in this study is cyclic, and this method allows a control lift to be used for normalization, this method was chosen for normalization in this study. This method may be contrasted with other normalization methods, e.g. using a maximum voluntary contraction (MVC) as a reference EMG signal. Although an MVC is proven to be a useful reference point, it includes the possibility that the subject fails to exert 100% of the maximum voluntary contraction [5]. Alternatively, using the method described above, the averaged peak muscle activation observed in the EMG signals from a controlled lift provides a reference from which the motion is known and repeatable. This normalization method yields a percentage of muscle activation that may be above or below the 100% controlled lift reference point.

The force plate data were also obtained, providing center of pressure location, as well as ground reaction forces and moments. However, these data were not addressed in this study, but will be useful for future analyses.

There were a total of 12 measured parameters. Six are angular or spatial measurements acquired from the motion capture data: torso angle, right hip angle, left hip angle, twist angle, shoulder elevation angle, moment arm. The remaining 6 parameters are EMG measurements from the six muscles previously defined.

Each trial was converted into a 100% cycle using a spline interpolation function. This allows the trials to be compared using the same number of data points. Each trial's cycle begins with the load on the floor just as the load begins to lift off the floor in the vertical direction. The cycle ends at 100% just as the load is set down and stops moving in the vertical direction.

With each trial's cycle established, three important values were measured for each parameter: mean value, peak value, and cumulative value. Each of these measurements is important as it may describe something unique about the data.

A mean value gives an average magnitude for a parameter in a given cycle. This parameter excludes duration and provides the geometric mean of the data. Although it may not describe the shape of the curve, it controls for the time varying effect of speed as it is not time dependent.

A peak value is used to measure one point at a particular event when the parameter is at its most severe or extreme value.

The cumulative value is important to consider because it includes duration combined with each data point over time. It may be important to consider how long a certain level of a parameter lasts. This is where a cumulative value is a useful and unique description of the data. For the purposes of simplicity in calculations, the cumulative value was calculated by multiplying the mean by the elapsed time to provide an approximation for the area under the curve.

Statistical Analysis

JMP v9.0 (SAS Institute) was used to perform the statistical analyses. The 12 parameters measured during the lifting trials yielded a numeric value for each of the three data descriptions (mean, peak, and cumulative), for a total of 36 independent variables to consider. The LAD design, asymmetry, and speed are taken as the three dependent variables in the model. Oneway analysis of variance (ANOVA) models were analyzed. All power analyses were performed using $\alpha=0.05$. Descriptive statistics and oneway ANOVAs were performed to analyze the responses of the survey data. For the analyses that showed statistical significance in the difference of means between groups, a post-hoc comparison using Tukey’s Honestly Significant Difference method was performed to identify the differences between pairs.

Missing Data

Although each participant was explicitly given the opportunity to discontinue the study at any time, or to not participate in any portion of the study, most participants attempted every part of the study. Most of the data that were not collected was the result of a participant finding a particular device to be uncomfortable to the point of choosing to discontinue using it. It should be noted that this occurred most frequently, but not always, with the Bending Device. The reasons for choosing to cease lifting with this device may be observed by the responses to the open-ended questions in the survey. These responses may be justified by noting that the bending device had the least padding, and was the heaviest of all of the devices.

CHAPTER 3

RESULTS

This chapter presents the results of the statistical analyses performed on the measured data, the survey data, and some additional observations that were made throughout this study.

The data obtained from measurements during lifting include six measurements from motion capture, and six EMG measurements. Of the six measurements from motion capture, five are angular measurements given in degrees, and one is a distance measurement given in millimeters. The EMG measurements were originally taken in voltages, but through processing and normalization, the measurements here are described as a percentage of the peak values measured while that particular subject performed a controlled lift (i.e. a forward floor to waist lift assigned to a 2-second duration). LADs are abbreviated as follows: Bending Device: BD, No Device: ND, Springzback: SB, Torsion Spring: TS.

EMG Data

Erector Spinae

The oneway ANOVA for mean right Erector Spinae (MRES) activity (p=0.002, power=0.913) is shown in Figure 12. Table 2 shows the grouping and the means for each LAD.

Figure 13 gives the results of the same comparison as in Figure 12, except that it

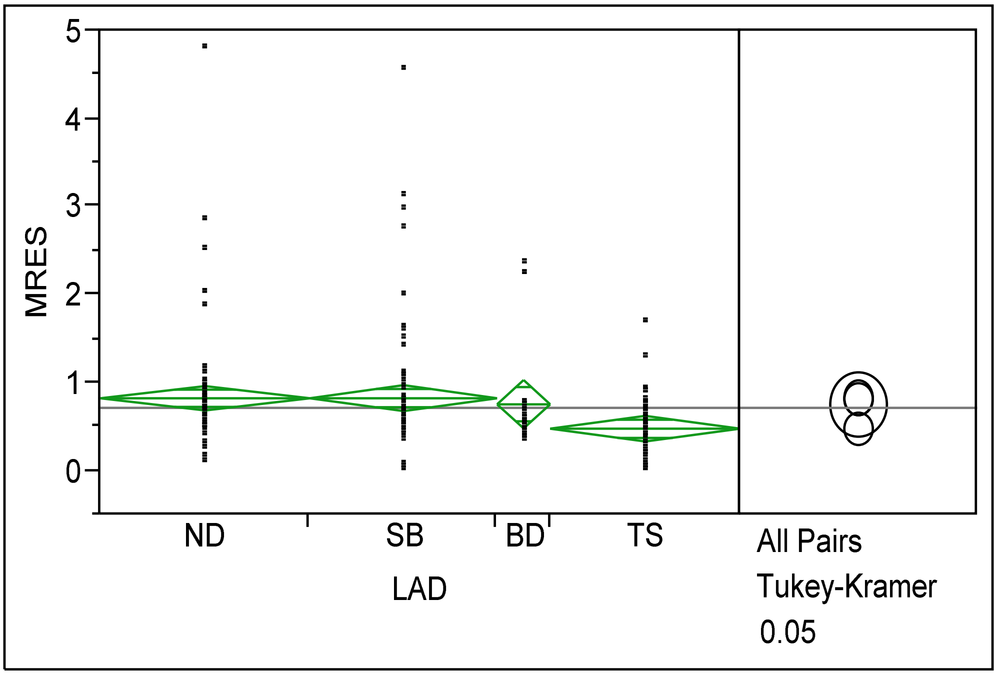


Figure 12 Oneway ANOVA for Mean Right Erector Spinae to LAD

Table 2 The grouping of devices comparing Mean Right Erector Spinae activity; each letter represents a statistically different group (p<0.05).

Device	Groups		Mean
Springzback	A		0.826
No Device	A		0.823
Bending Device	A	B	0.757
Torsion Spring		B	0.477

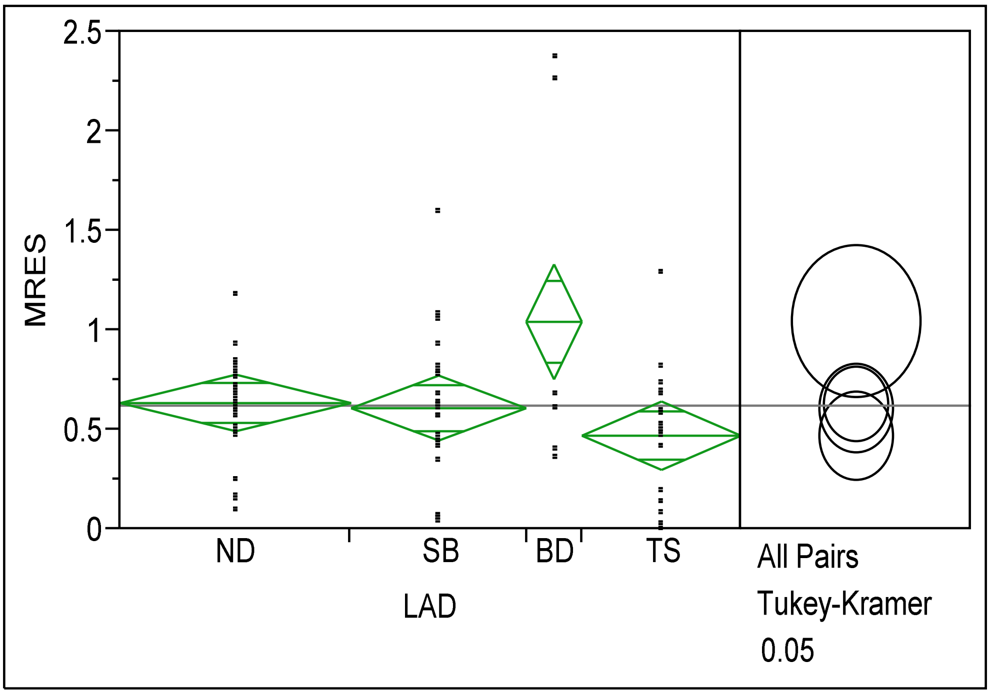


Figure 13 Oneway ANOVA for Mean Right Erector Spinae Activity for Forward Lifts by LAD

specifies that it only includes data from forward lifts. There was a statistically significant difference between devices (p=0.013, power=0.800), and Table 3 shows the grouping and means for each LAD.

The MRES activity across LADs is given for left lifts in Figure 14 (p=0.029, power=0.714). Table 4 shows the grouping and means for each LAD.

The MRES activity across LADs is given for right lifts in Figure 15 (p=0.029, power=0.714). Table 5 shows the grouping and means for each LAD.

The peak right Erector Spinae (PRES) and cumulative right Erector Spinae (CRES) activity analyses show the same pattern in order of severity to the MRES shown in Figure 13, and were all statistically significant ($p<0.05$), with one exception, as shown in Table 6.

Table 3 The grouping of devices comparing Mean Right Erector Spinae Activity for Forward Lifts; each letter represents a statistically different group (p<0.05).

Device	Groups		Mean
Bending Device	A		1.044
No Device	A	B	0.636
Springzback	A	B	0.611
Torsion Spring		B	0.472

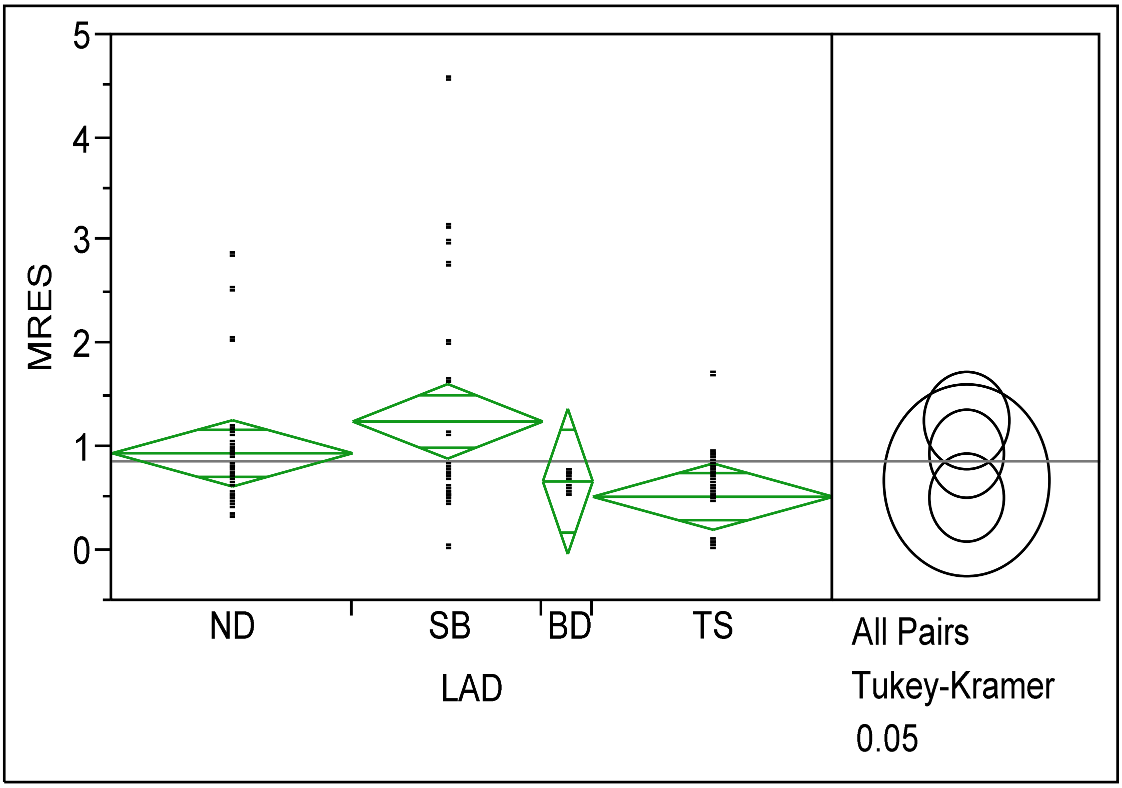


Figure 14 Oneway ANOVA for Mean Right Erector Spinae Activity for Left Lifts by LAD

Table 4 The grouping of devices comparing Mean Right Erector Spinae Activity for Left Lifts; each letter represents a statistically different group ($p<0.05$).

Device	Groups		Mean
Springzback	A		1.249
No Device	A	B	0.940
Bending Device	A	B	0.667
Torsion Spring		B	0.518

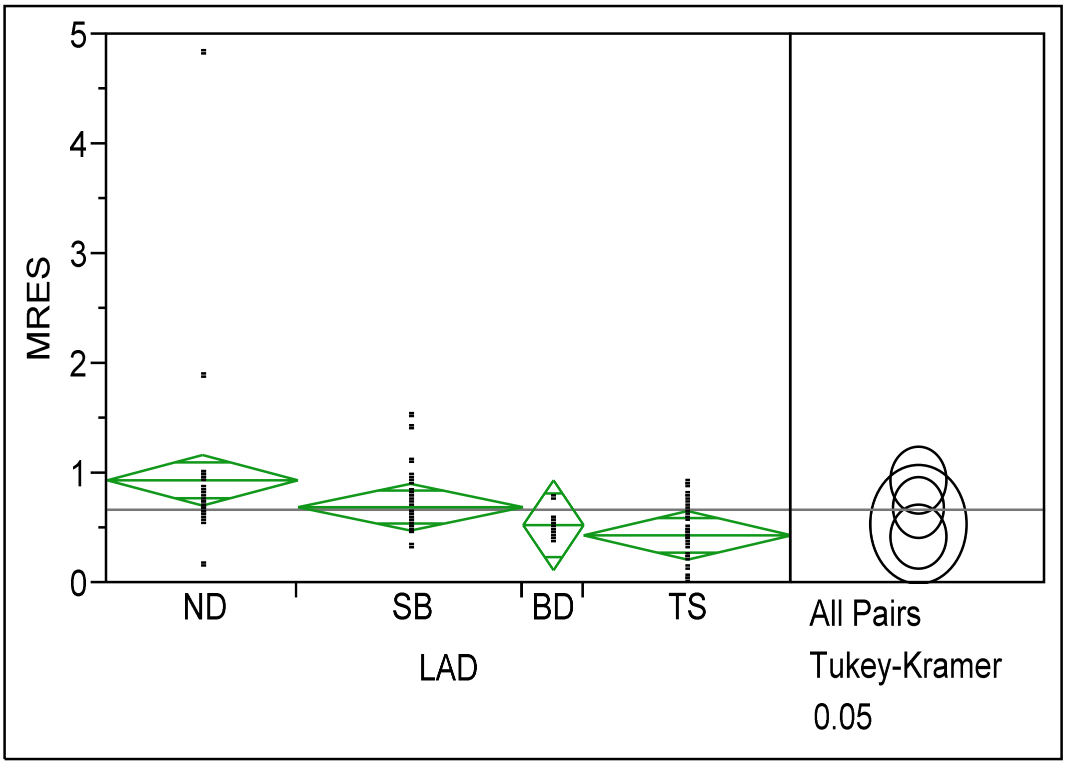


Figure 15 Oneway ANOVA for Mean Right Erector Spinae Activity for Right Lifts to LAD

Table 5 The grouping of devices comparing Mean Right Erector Spinae Activity for Right Lifts; each letter represents a statistically different group (p<0.05).

Device	Groups		Mean
No Device	A		0.943
Springzback	A	B	0.699
Bending Device	A	B	0.533
Torsion Spring		B	0.441

Table 6 Results for Oneway Analyses PRES and CRES Activity to LAD

Oneway Analysis	p value	Power
PRES by LAD, Twist = Forward	**0.002**	0.937
PRES by LAD, Twist = Left	0.051	0.635
PRES by LAD, Twist = Right	**<0.001**	0.983
CRES by LAD, Twist = Forward	**0.013**	0.800
CRES by LAD, Twist = Left	**0.029**	0.714
CRES by LAD, Twist = Right	**0.022**	0.748

The ANOVA for PRES by LAD for left lifts was trending toward significance, and nearly follows the same pattern in the order of severity as shown in the results for MRES in Table 4. The exception to this is that the Springzback device shows a slightly lower mean PRES than with ND. This is shown in Figure 16 and Figure 13.

Rectus Abdominus

The mean right Rectus Abdominus (MRRA) activity across LADs is given for all lifts in Figure 17, and was found to be trending towards statistical significance ($p=0.057$).

The mean left Rectus Abdominus (MLRA) activity across LADs is given for all lifts in Figure 18 ($p=0.003$, power=0.893). Table 8 shows the grouping and means for each LAD.

The p value and power from the ANOVA of MRRA, peak right Rectus Abdominus (PRRA), and cumulative right Rectus Abdominus (CRRA) activity compared to LAD by twist is shown in Table 9.

Each of the above analyses for forward lifts were found to be significant with a similar pattern. This is shown in Figure 19 and Table 10 where the Springzback device increases muscle activity the most, followed by the Torsion Spring device. The Bending Device caused a reduction in muscle activity.

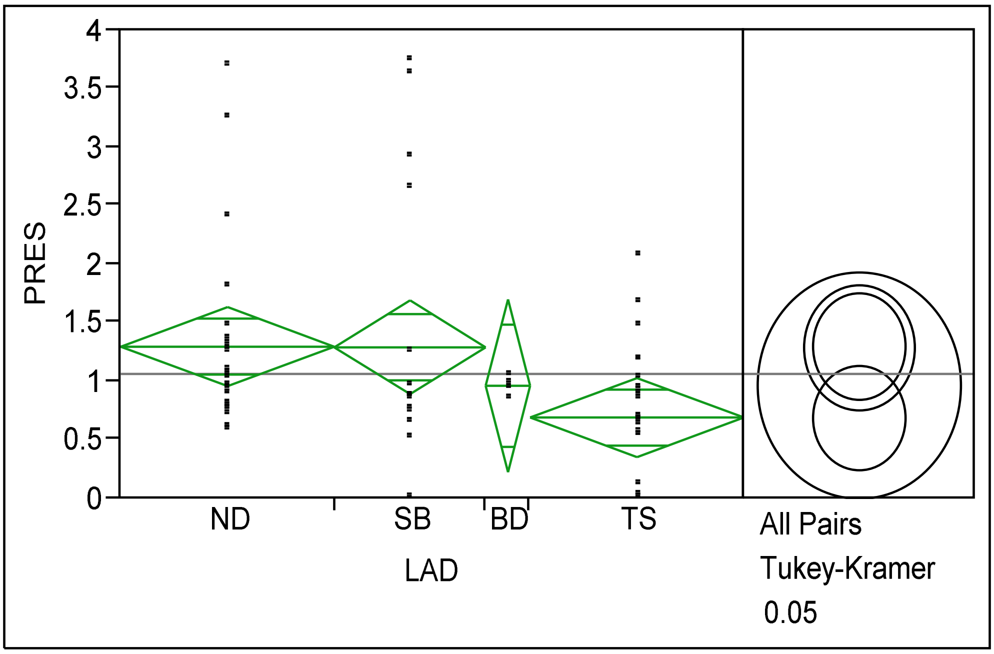


Figure 16 Oneway ANOVA for Peak Right Erector Spinae Activity for Left Lifts by LAD

Table 7 The Device Mean Values for Mean Right Erector Spinae Activity for Left Lifts

Device	Mean
No Device	1.300
Springzback	1.294
Bending Device	0.964
Torsion Spring	0.693

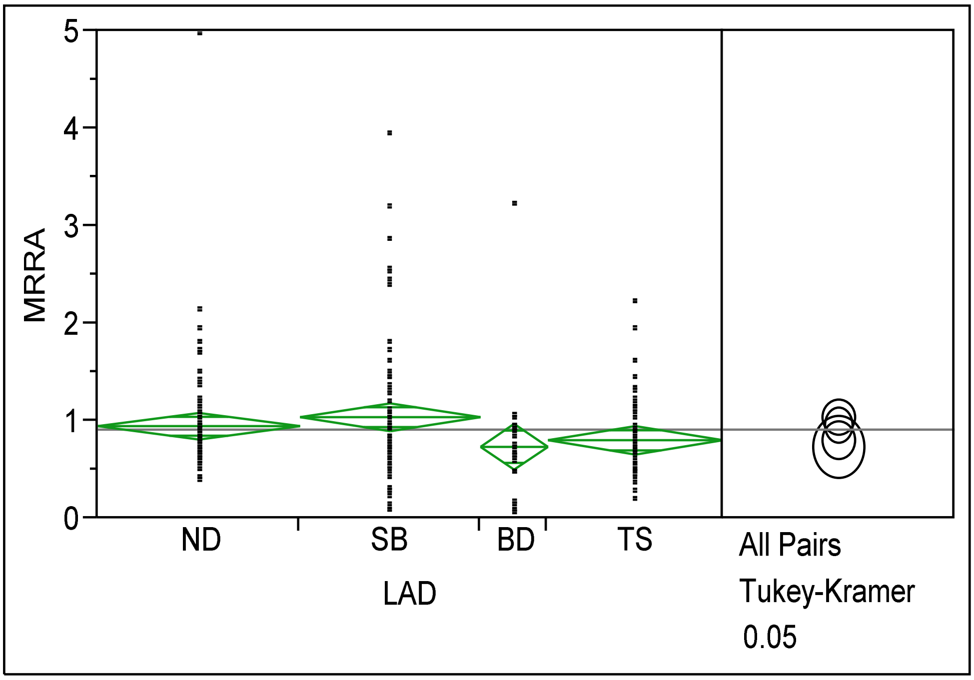


Figure 17 Oneway ANOVA for Mean Right Rectus Abdominus Activity for All Lifts to LAD

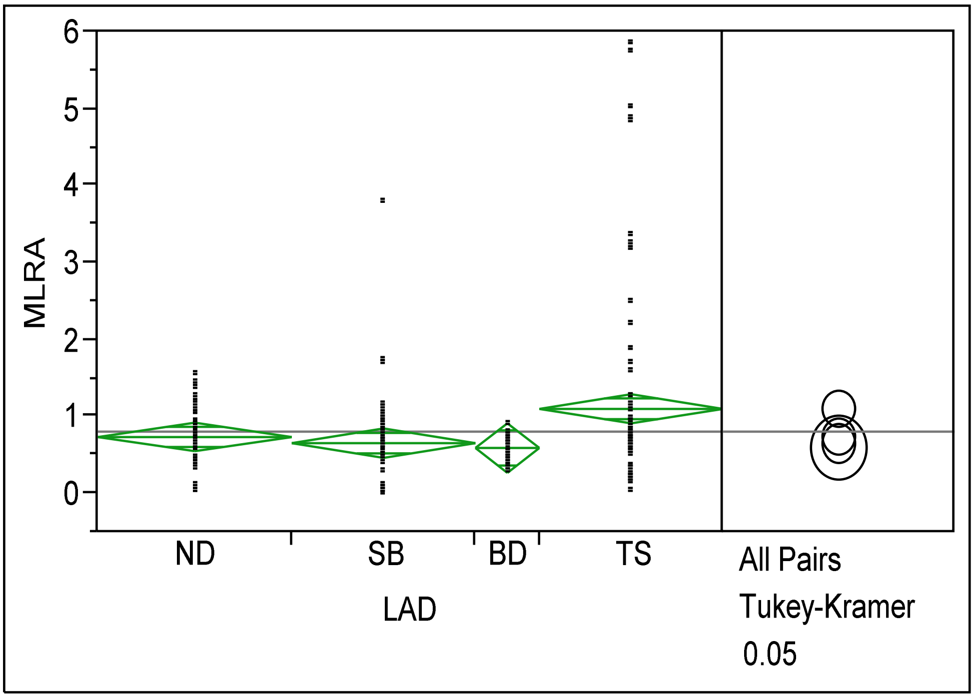


Figure 18 Oneway ANOVA for Mean Left Rectus Abdominus Activity for All Lifts to LAD

Table 8 The grouping of devices comparing Mean Right Rectus Abdominus Activity for Right Lifts; each letter represents a statistically different group ($p<0.05$).

Device	Groups		Mean
Torsion Spring	A		1.105
No Device		B	0.738
Springzback		B	0.660
Bending Device		B	0.595

Table 9 Results for Oneway Analyses MRRA, PRRA and CRRA by LAD

Oneway Analysis	p value	Power
MRRA by LAD, Twist = Forward	**0.012**	0.807
MRRA by LAD, Twist = Left	0.078	0.569
MRRA by LAD, Twist = Right	0.131	0.481
PRRA by LAD, Twist = Forward	**0.013**	0.803
PRRA by LAD, Twist = Left	0.114	0.505
PRRA by LAD, Twist = Right	0.151	0.455
CRRA by LAD, Twist = Forward	**0.027**	0.721
CRRA by LAD, Twist = Left	**0.017**	0.777
CRRA by LAD, Twist = Right	0.132	0.481

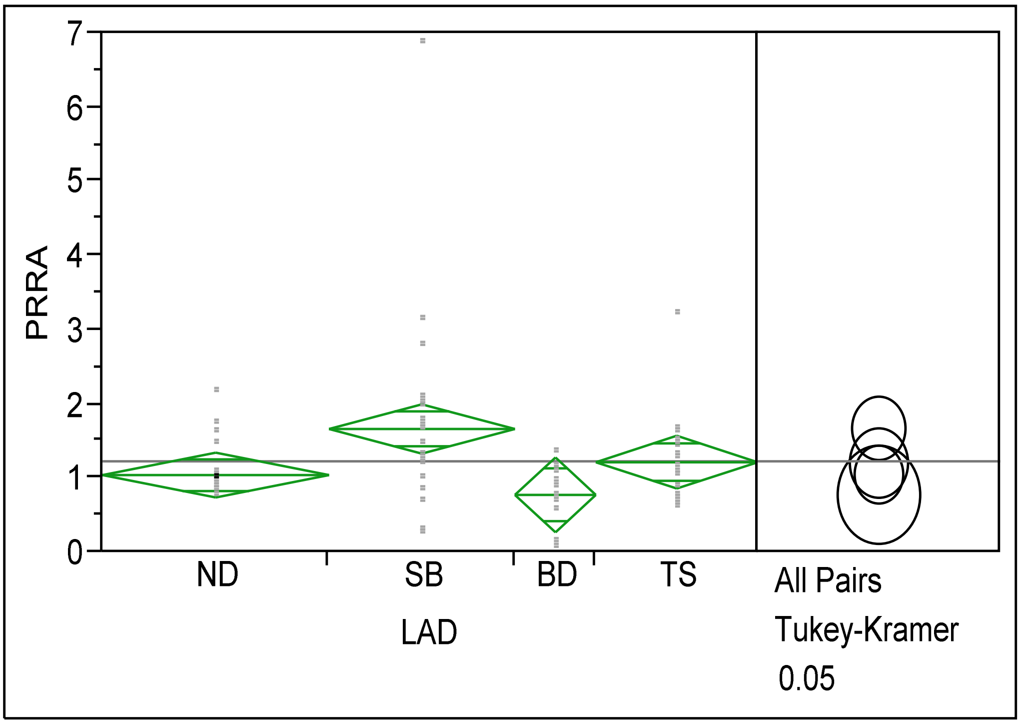


Figure 19 Oneway ANOVA for Peak Right Rectus Abdominus Activity for Forward Lifts to LAD

Table 10 The grouping of devices comparing Peak Right Rectus Abdominus Activity for Forward Lifts; each letter represents a statistically different group (p<0.05).

Device	Groups		Mean
Springzback	A		1.666
Torsion Spring	A	B	1.218
No Device		B	1.042
Bending Device		B	0.777

External Oblique

The mean right External Oblique (MREO) activity across LADs is given for all lifts in Figure 20 ($p<0.001$, power=1.000). Table 11 shows the grouping and means for each LAD.

The mean left External Oblique (MLEO) activity across LADs is given for all lifts in Figure 21 ($p<0.001$, power=1.000). Table 12 shows the grouping and means for each LAD.

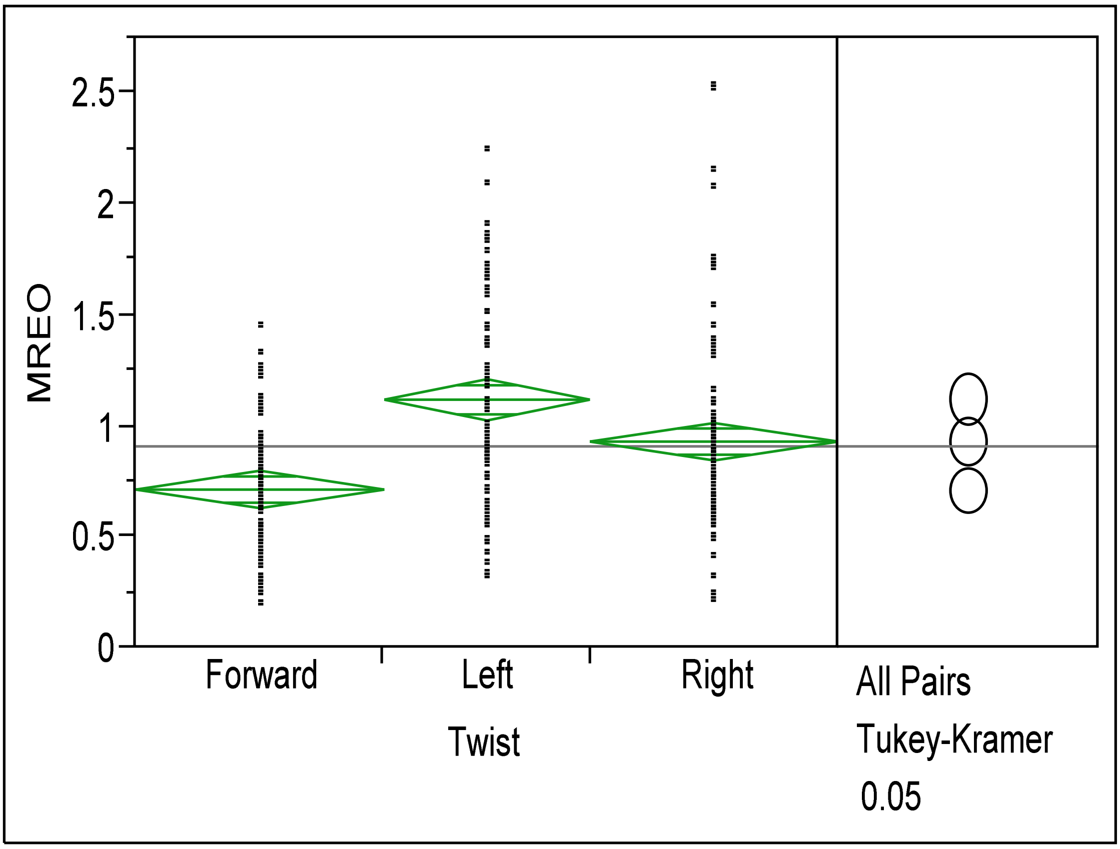


Figure 20 Oneway ANOVA for Mean Right External Oblique Activity to Twist

Table 11 The grouping of Twist comparing Mean Right External Oblique Activity for Right Lifts; each letter represents a statistically different group (p<0.05).

Device	Groups	Mean
Left	A	1.120
Right	B	0.931
Forward	C	0.715

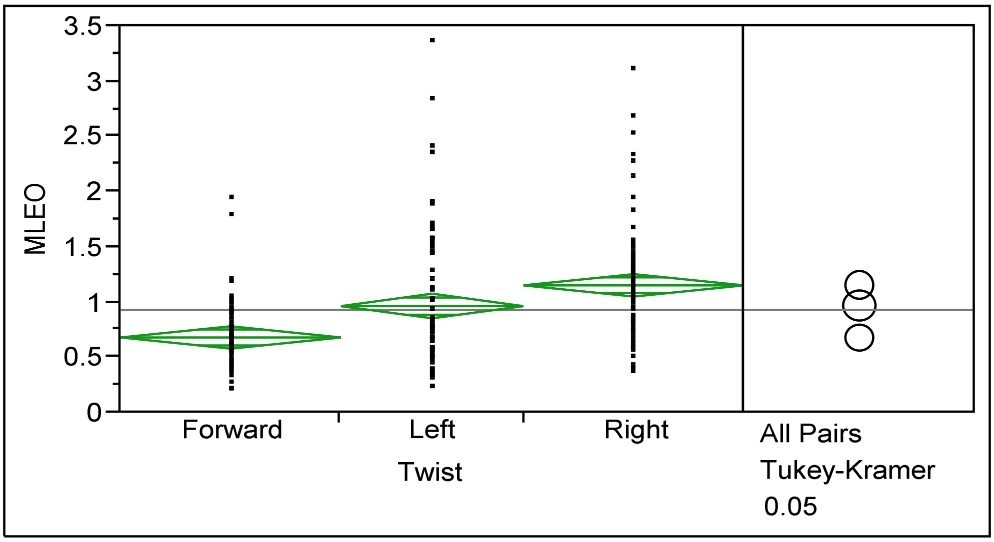


Figure 21 Oneway ANOVA for Mean Left External Oblique Activity to Twist

Table 12 The grouping of Twist comparing Mean Left External Oblique Activity for Right Lifts; each letter represents a statistically different group (p<0.05).

Device	Groups	Mean
Right	A	1.154
Left	B	0.966
Forward	C	0.681

Motion Capture Data

The statistical analysis of the motion capture data provided many statistically significant relationships. The trajectorized motion capture data from the ARENA software was exported to C3D files. The data from C3D files were copied into an Excel spreadsheet, and processing and calculations were performed using custom LabVIEW software.

Figure 22 shows a box plot of the difference in means (p=0.019) when the mean moment arm (given in mm) was compared between devices (abbreviated Bending Device: BD, No Device: ND, Springzback: SB, Torsion Spring: TS) for forward lifts (power = 0.764). Table 13 shows the grouping and the means for each group.

Figure 23 shows a trend that is similar to the results from the Mean Moment Arm in Figure 22. However, in this case the groups were not found to be significantly different. Table 14 also shows similar trends of means to Table 13.

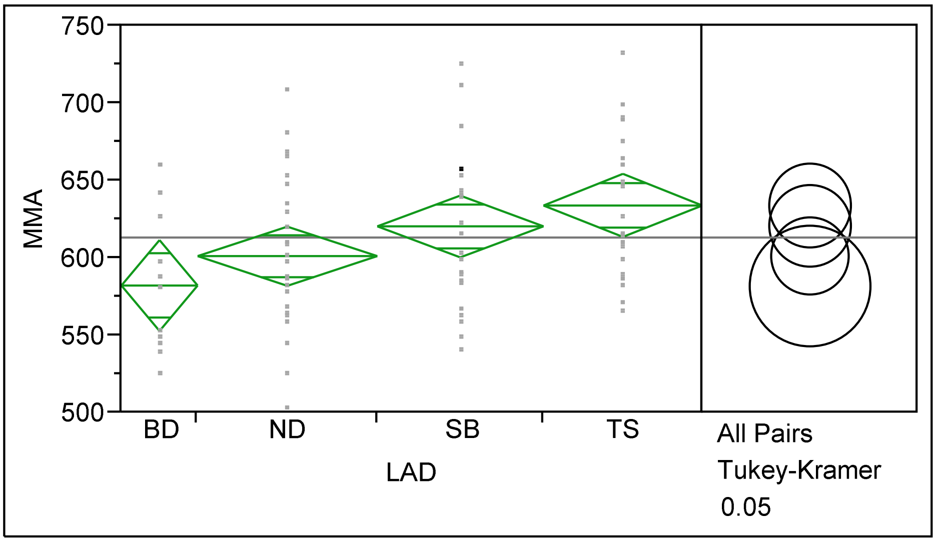


Figure 22 Oneway ANOVA for Mean Moment Arm (mm) by LAD for forward lifts

Table 13 The grouping of devices comparing Mean Moment Arm; each letter represents a statistically different group (p<0.05).

Device	Groups		Mean
Torsion Spring	A		634
Springzback	A	B	620
No Device	A	B	601
Bending Device		B	582

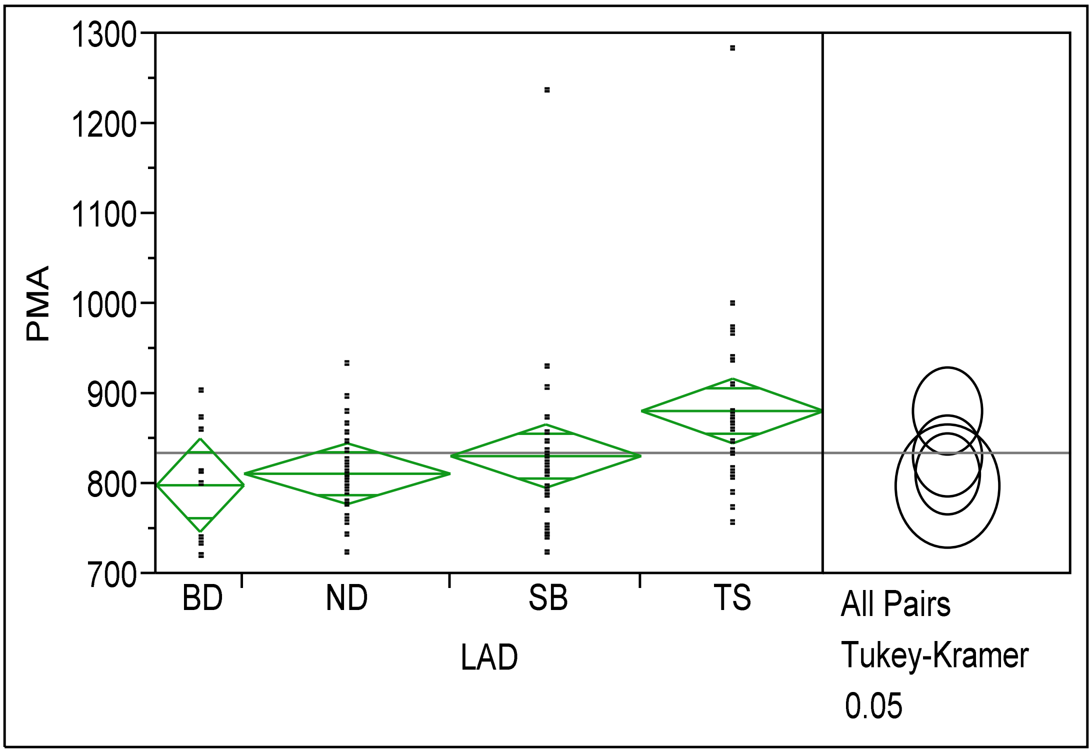


Figure 23 Oneway ANOVA for Peak Moment Arm (mm) to LAD for forward lifts

Table 14 The Means of devices comparing Peak Moment Arm; each letter represents a statistically different group (p<0.05).

Device	Mean
Torsion Spring	846
Springzback	832
No Device	812
Bending Device	800

Figure 24 shows the difference between devices for the Peak Torso Angle parameter ($p=0.002$) for forward lifts only (power = 0.920). Table 15 gives Tukey's HSD post-hoc test.

As shown in Table 15, Tukey's HSD post-hoc test revealed that the Springzback Device is the only device in the same group as No Device. However, all three of the devices are shown to cause a difference in lifting technique in that the user maintains a more bent posture.

The mean angle of twist (MTW) for forward lifts showed significant differences between devices ($p<0.001$) with (power=0.999). Figure 25 shows the box plot of the grouped data in relation to one another, and Table 16 gives the grouping and mean for each LAD's MTW.

The cumulative angle of twist (CTW) showed similar differences between devices ($p<0.001$) with (power=0.999) as displayed in the box plot in Figure 26, and the grouping and means in Table 17.

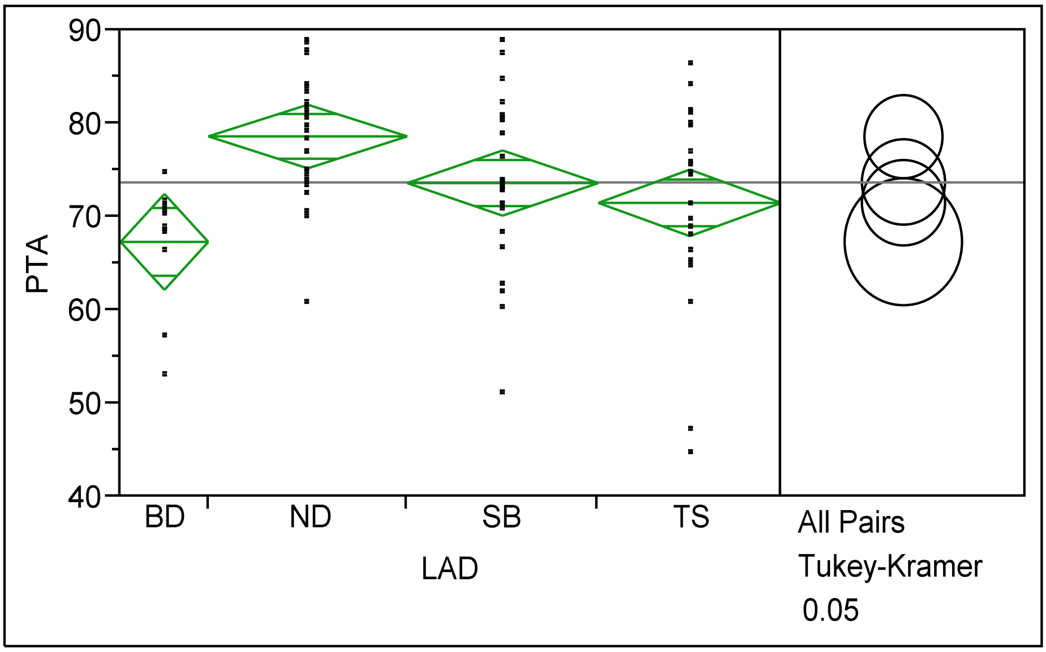


Figure 24 Oneway ANOVA for Peak Torso Angle (deg) to LAD for forward lifts

Table 15 The grouping of devices comparing Peak Torso Angle (deg); each letter represents a statistically different group ($p<0.05$).

Device	Groups		Mean
No Device	A		78.6
Springzback	A	B	73.6
Torsion Spring		B	71.5
Bending Device		B	67.3

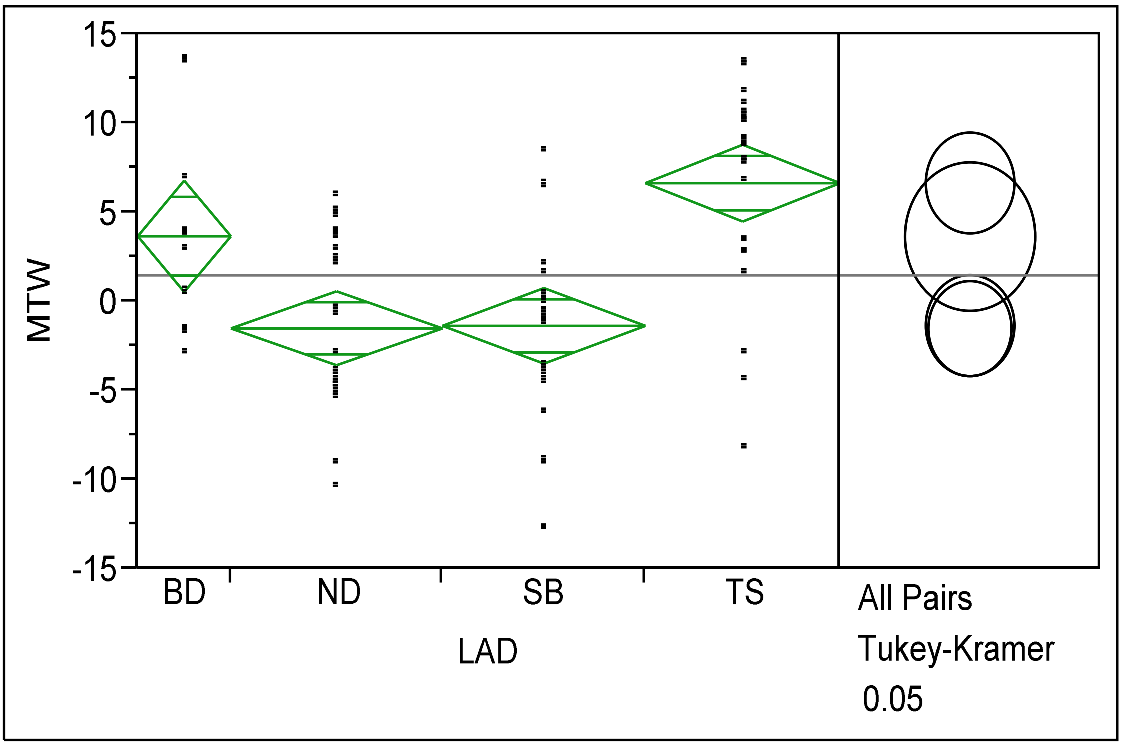


Figure 25 Oneway ANOVA for Mean Twist Angle (deg) by LAD for forward lifts

Table 16 The grouping of devices comparing Mean Twist Angle (deg); each letter represents a statistically different group (p<0.05).

Device	Groups		Mean
Torsion Spring	A		6.7
Bending Device	A		3.7
Springzback		B	-1.4
No Device		B	-1.5

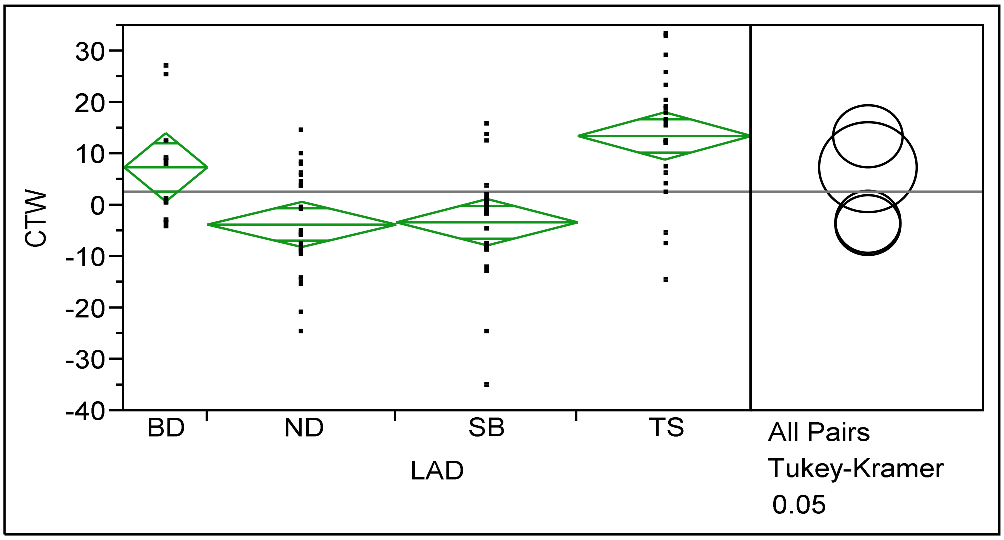


Figure 26 Oneway ANOVA for Cumulative Twist Angle (deg) to LAD for forward lifts

Table 17 The grouping of devices comparing Cumulative Twist Angle (deg); each letter represents a statistically different group (p<0.05).

Device	Groups		Mean
Torsion Spring	A		13.6
Bending Device	A		7.4
Springzback		B	-3.2
No Device		B	-3.6

<u>Survey Data</u>

The second question on the questionnaire allowed the participants to give a rating of comfort for each device by simply asking, "Was the device comfortable?" The oneway ANOVA did not yield statistical significance (p=0.1525) for this question across devices. Table 18 shows the mean, range, and standard deviation (SD) for the comfort level rating of each device. The comfort ratings for each device were displayed on a bar

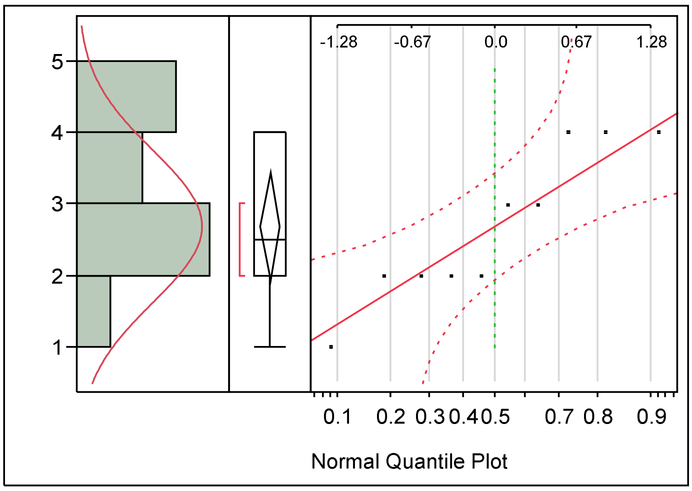
Table 18 Participant comfort rating statistics for each device

	Springzback	Bending Device	Torsion Spring
Min	1	1	1
Max	4	3	4
Mean	2.7	1.8	2.4
Range	3	2	3
SD	1.06	0.79	1.17

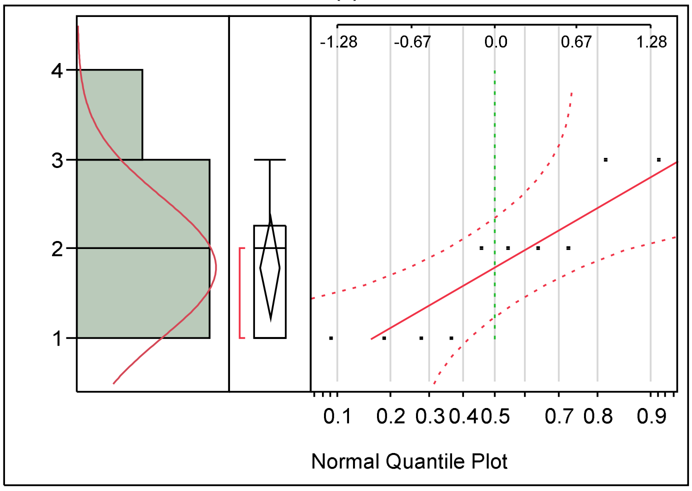
plot and fitted to a normally distributed curve. Figure 27 displays the plots and curves as well as a normal quantile plot for each.

Question 7 was, “Does the weight of the device cause discomfort?” Again, the oneway ANOVA did not yield statistical significance (p=0.496) for this question; however, important information about discomfort levels due to weight may be drawn from the descriptive statistics shown in Table 19. The discomfort ratings for each device were plotted on a bar plot and fitted to a normally distributed curve. Figure 28 displays the plots and curves as well as a normal quantile plot, showing normality for each.

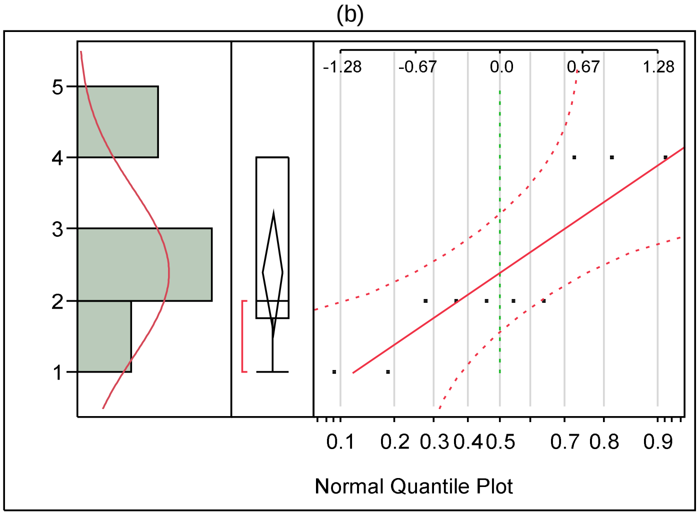
After comparing means using oneway ANOVA for each of the nine survey questions, it was found that only two yielded statistical significance (p<0.05), and one was trending towards significance. Table 20 shows the variance values for the oneway ANOVA for question 1, and a box plot of the statistical analysis is shown in Figure 29. Table 21 shows the statistically significant grouping of the devices according to the responses of question 1. Table 22 shows the variance values for the oneway ANOVA for question 3, and a box plot of the statistical analysis is shown in Figure 30. Table 23 shows the statistically significant grouping of the devices according to the responses of



(a)



(b)

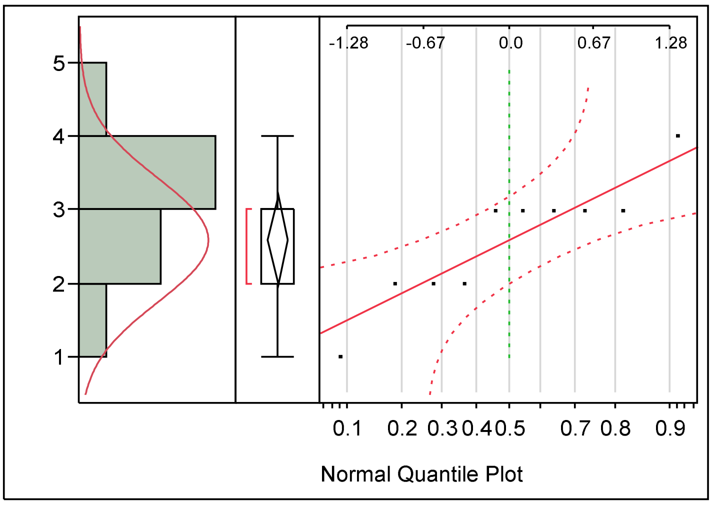


(c)

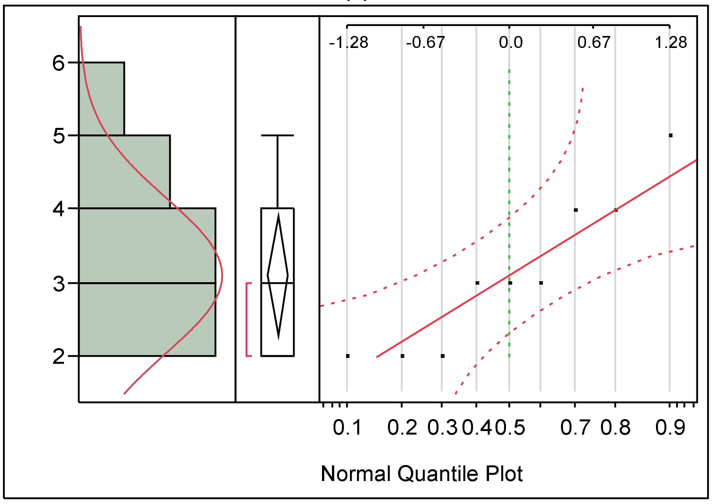
Figure 27 Comfort response bar plots fitted to normal curves with normal quantile plots for (a) Springzback Device, (b) Bending Device, (c) Torsion Spring Device

Table 19 Participant discomfort rating descriptive statistics for each device

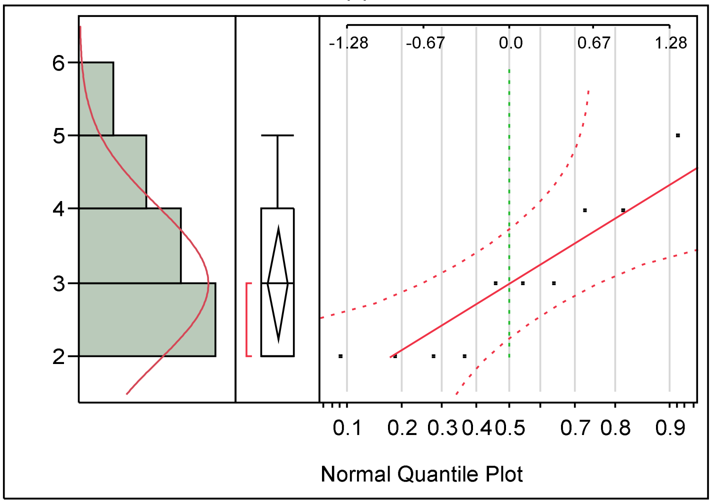
	Springzback	Bending Device	Torsion Spring
Min	1	2	2
Max	4	5	5
Mean	2.6	3.1	3.0
Range	3	3	3
SD	0.84	1.05	1.05



(a)



(b)



(c)

Figure 28 Discomfort response bar plots fitted to normal curves with quantile plots for (a) Springzback Device, (b) Bending Device, (c) Torsion Spring Device

Table 20 Analysis of variance for question 1:
"Was the device easy to put on and take off?"

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Device	2	9.266	4.633	4.088	**0.028**
Error	27	30.600	1.133		
C. Total	29	39.866			

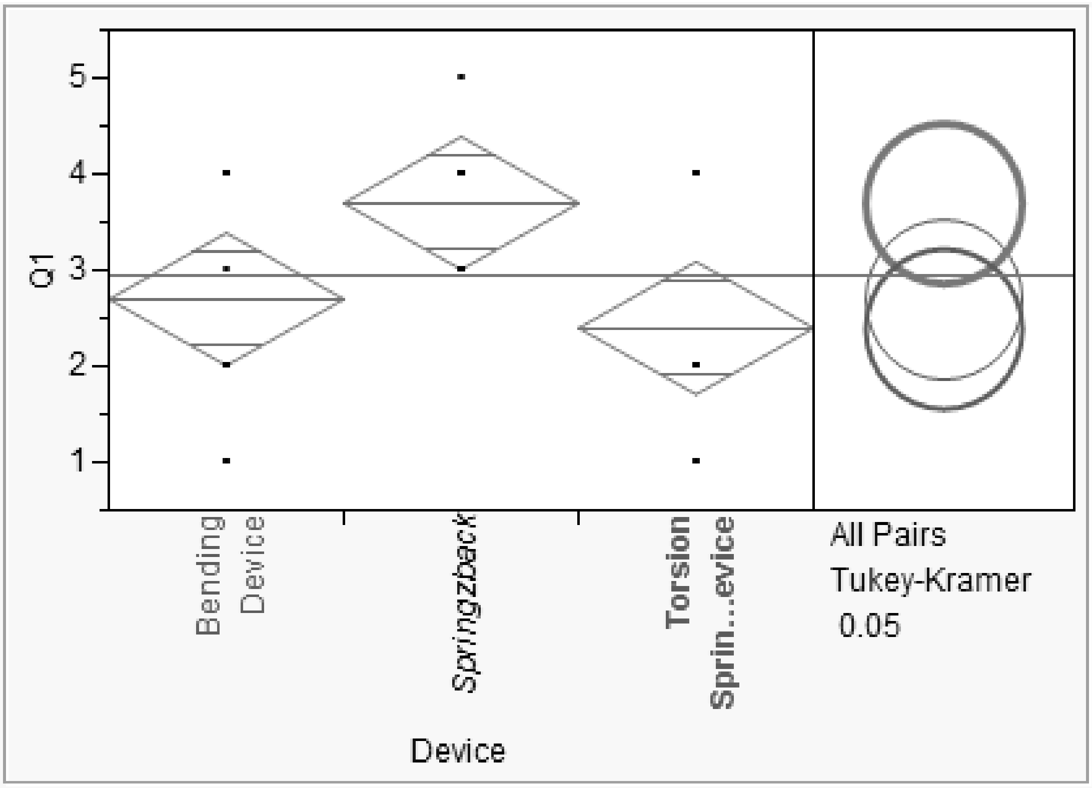


Figure 29 Oneway ANOVA Box Plot for Question 1 with Tukey-Kramer Comparison

Table 21 The grouping of devices depending on question 1; each letter represents a statistically different group ($p<0.05$).

Device	Groups		Mean
Springzback	A		3.70
Bending Device	A	B	2.70
Torsion Spring		B	2.40

Table 22 Analysis of variance for question 3:
"Does the device adjust to fit you well?"

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Device	2	6.866	3.433	3.498	**0.045**
Error	27	26.500	0.981		
C. Total	29	33.366			

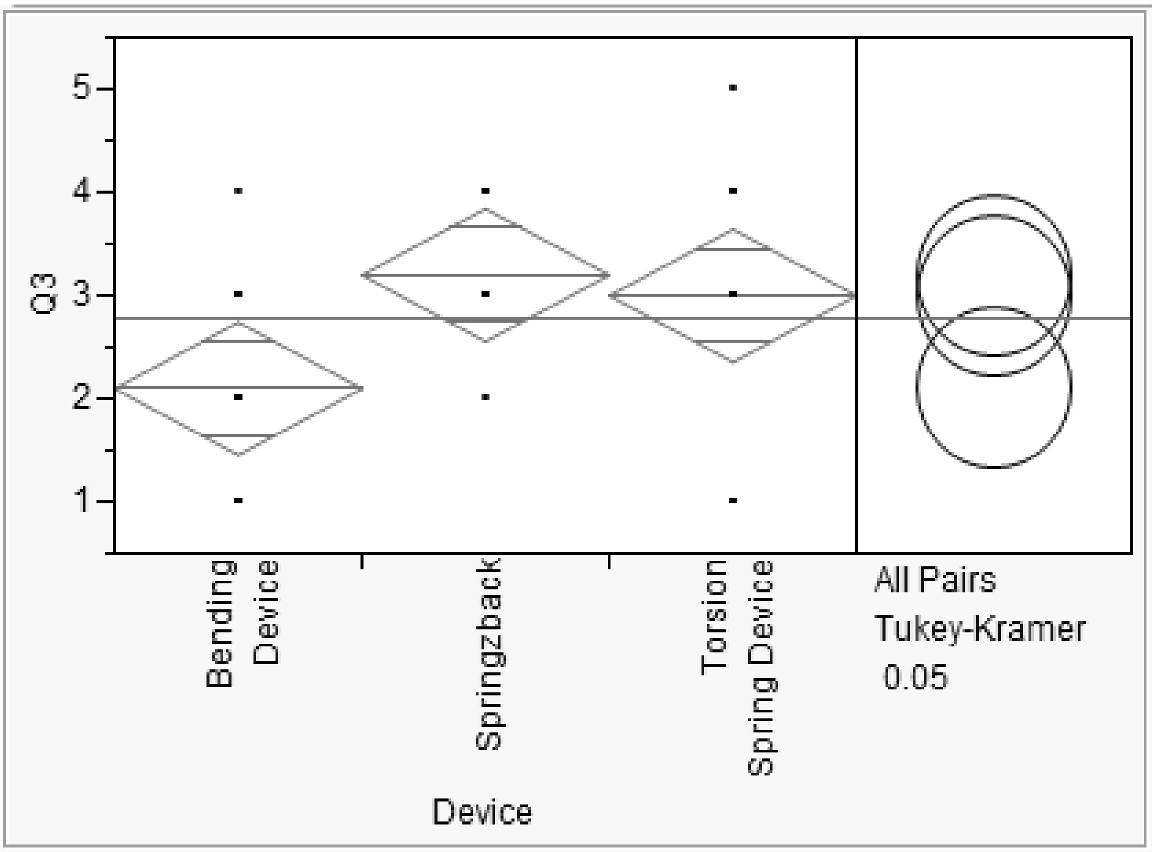


Figure 30 Oneway ANOVA Box Plot for Question 3 with Tukey-Kramer Comparison

Table 23 The grouping of devices depending on question 3; each letter represents a statistically different group (p<0.05).

Device	Groups		Mean
Springzback	A		3.20
Torsion Spring	A	B	3.00
Bending Device		B	2.10

question 3. Table 24 shows the variance values for the oneway ANOVA for question 1, and a box plot of the statistical analysis is shown in Figure 31.

The oneway ANOVA yielded statistical significance, and in the Tukey-Kramer Post-Hoc test, the difference between the Springzback and Torsion Spring device is statistically different (p = 0.0287).

The oneway ANOVA yielded a statistically significant result, and in the Tukey-Kramer Post Hoc test, the difference between the Springzback and Bending Device is statistically different (p = 0.0496). The means may also be noted to be in descending order of adjustability as Springzback, Torsion Spring Device, then Bending Device.

Table 24 Analysis of Variance for Question 9: “Does the device look appealing?”

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Device	2	5.582	2.791	2.732	**0.084**
Error	26	26.555	1.021		
C. Total	28	32.137			

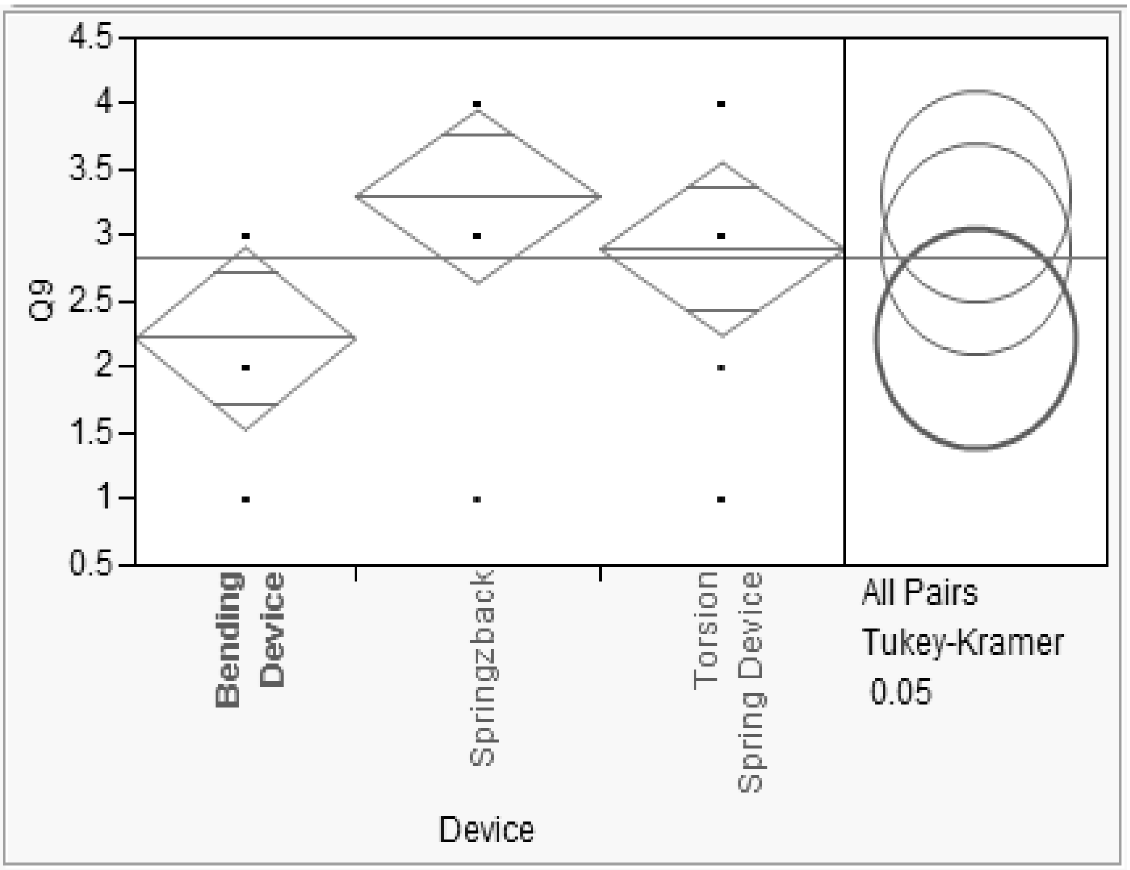


Figure 31 Oneway ANOVA Box Plot for Question 9 with Tukey-Kramer Comparison

Subjective Responses from the Survey

Three open-ended free-response questions were given to each participant for each device individually. This allowed each participant to communicate something about his experience with each device. To summarize these results, some of the responses that appeared to be common across participants are given in Table 25,Table 26 and Table 27. Each question is also included in the tables.

Table 25 Subjective responses for the bending device

Q: What is the hardest or worst part about using this device?
• "Hard to put on" • "Lack of padding especially where it presses on rear of knees." • "Limited range of motion. Required additional force to reach the box." • "Difficult to bend"
Q: If you could change one thing about this device, what would it be?
• "Increase the padding" • "Height adjustability" • "Bending members should be redesigned" • "Make the device more adjustable to fit the person"
Q: What aspects of the device seem awkward, uncomfortable, unsafe, or more difficult than necessary?
• "The orange spring parts stabbed at the crook of my knees." • "I had to have straps on legs loose so that I could reach the box on the floor." • "Too heavy, hard to put on. It hurts my back too."

Table 26 Subjective responses for the Springzback device

Q: What is the hardest or worst part about using this device?
• "The chest piece hurt where it pressed on me." • "Chest pad goes up to my neck when I bend fully forward" • "The leg attachments would shift and dig into my legs with slight twisting" • "Making sure that it is properly fitted. Maybe too many adjustments"
Q: If you could change one thing about this device, what would it be?
• "More padding." • "Provide padding for the leg and chest pads with a slick covering for not catching on cloths, etc." • "Upper support would rub in my chest"
Q: What aspects of the device seem awkward, uncomfortable, unsafe, or more difficult than necessary?
• "Hard plastic was uncomfortable." • "Thigh pad is a little too hard" • "Sharp edges of each support made me uncomfortable, especially during the fast pace work." • "Gave little support to lifting."

Table 27 Subjective responses for the torsion spring device

Q: What is the hardest or worst part about using this device?
• "Difficulty turning" • "Heavy weight. Leg support" • "It would not stay in position it felt like it should be." • "Putting on and taking off"
Q: If you could change one thing about this device, what would it be?
• "Wider range of turning available" • "I would make the leg pads so they could pivot to stay totally in contact with leg so as not to concentrate in one area" • "Make it lighter and more adjustable (leg support)"
Q: What aspects of the device seem awkward, uncomfortable, unsafe, or more difficult than necessary?
• "I didn't feel free to move. It seemed very restrictive." • "Seemed bulky but not too heavy" • "It's easier and more comfortable to do the task with out the device."

<u>Additional Observations</u>

Figure 32 shows the torso angle for a forward lift with no device for each of the three lifting speeds.

Figure 33 shows the moment arm for a forward lift cycle with no device for each of the three lifting speeds. Figure 34 shows the torso angle for a forward lift cycle with the Torsion Spring device for each of the three lifting speeds.

Figure 35 shows the moment arm for a forward lift cycle with the Torsion Spring device for each of the three lifting speeds.

Figure 36 shows the moment arm for a right twist lift cycle with each of the four LAD scenarios. Figure 37 shows the processed EMG signal for one of the Erector Spinae muscles during a forward, medium duration lift with no LAD. The three curves displayed here were chosen to show similarities and contrasts between participants' data. Only the data from participants 2, 5, and 8 are shown so as to not clutter the chart.

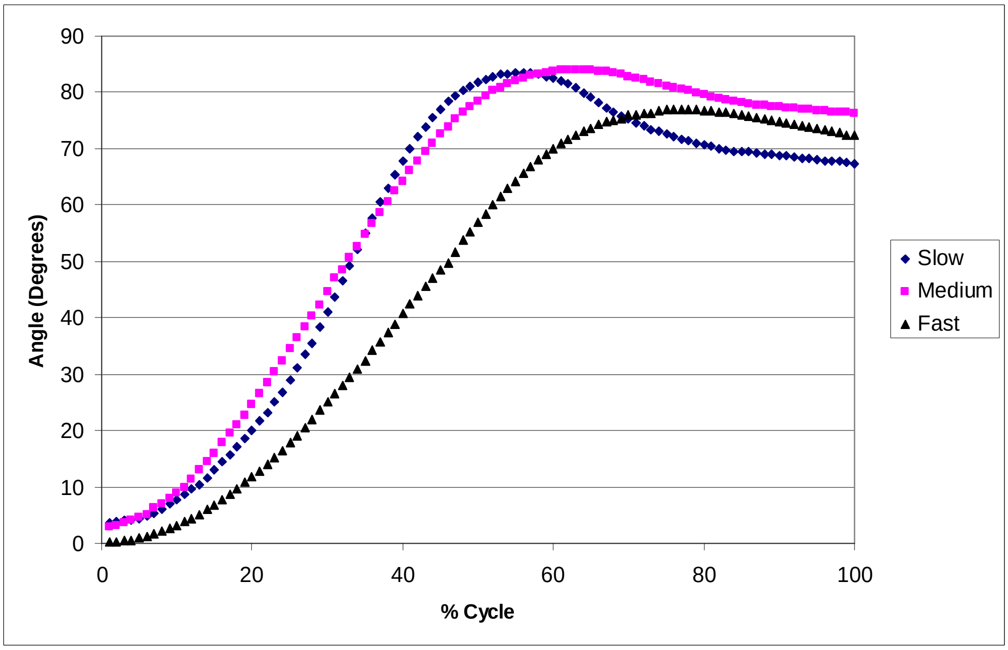


Figure 32 Torso Angle for Forward Lift Cycle with No Device

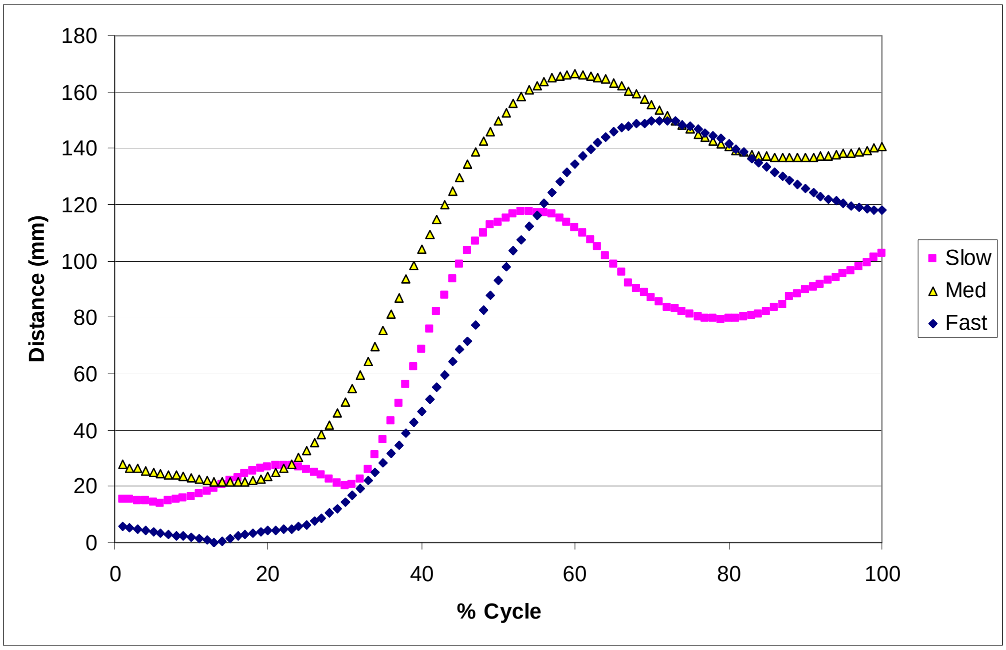


Figure 33 Moment Arm for Forward Lift Cycle with No Device

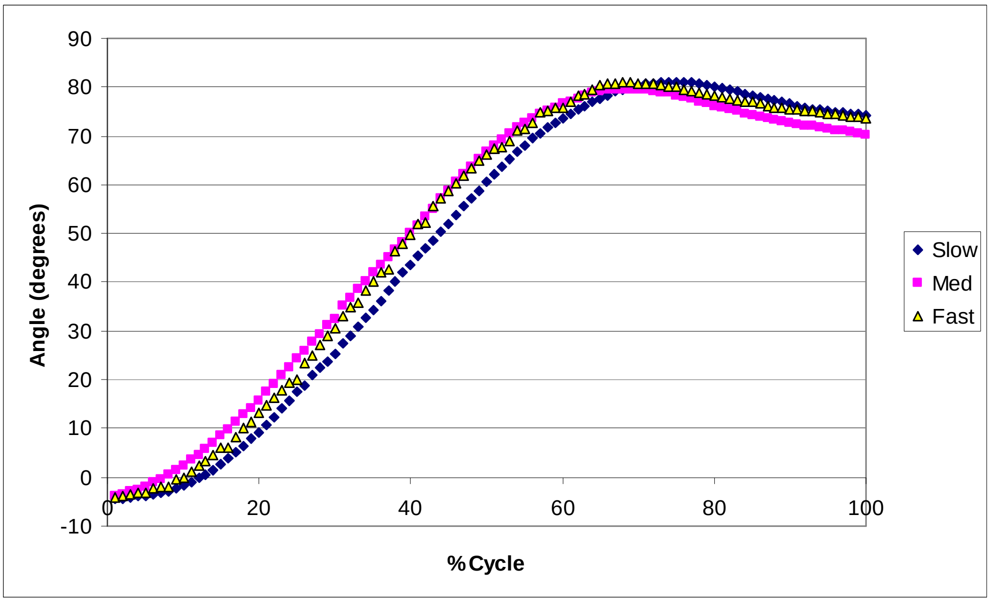


Figure 34 Forward Lift Cycle - Torso Angle Torsion Spring

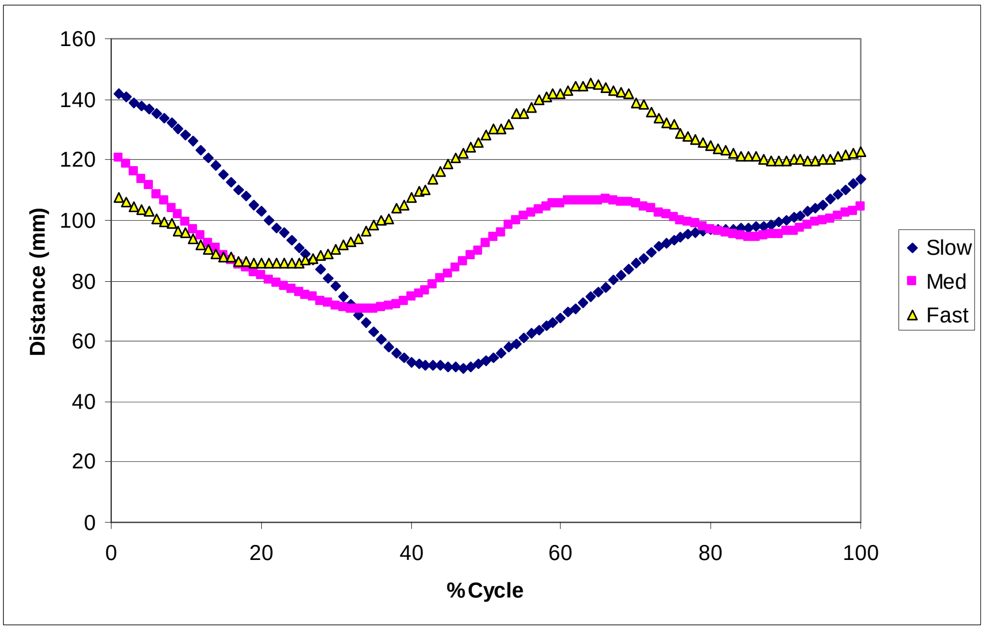


Figure 35 Forward Lift Cycle - Moment Arm Torsion Spring

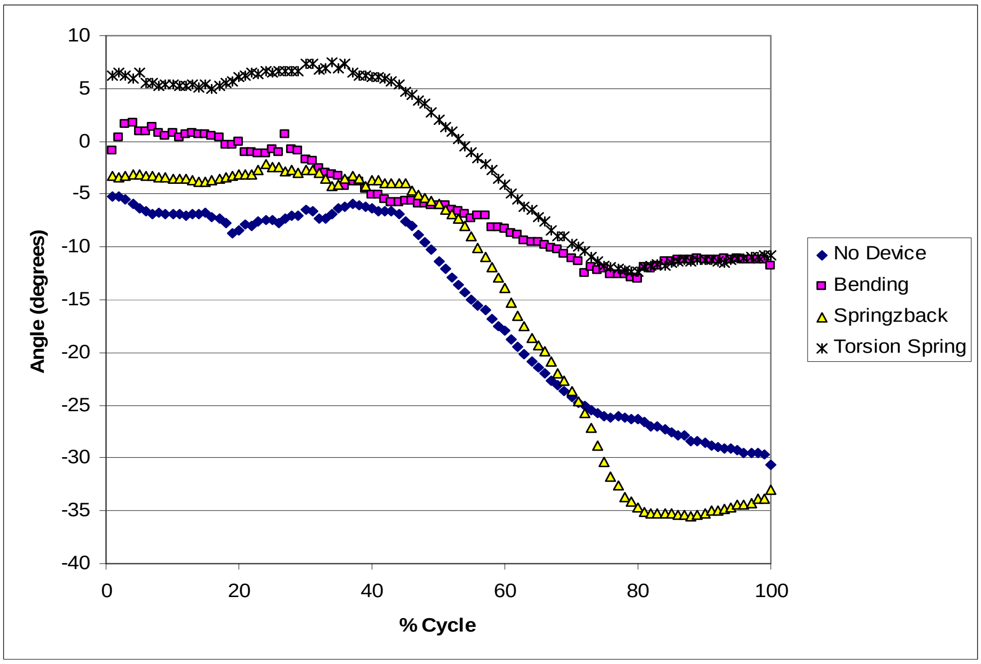


Figure 36 Right Twist Lift Cycle - Twist Angle Medium Speed

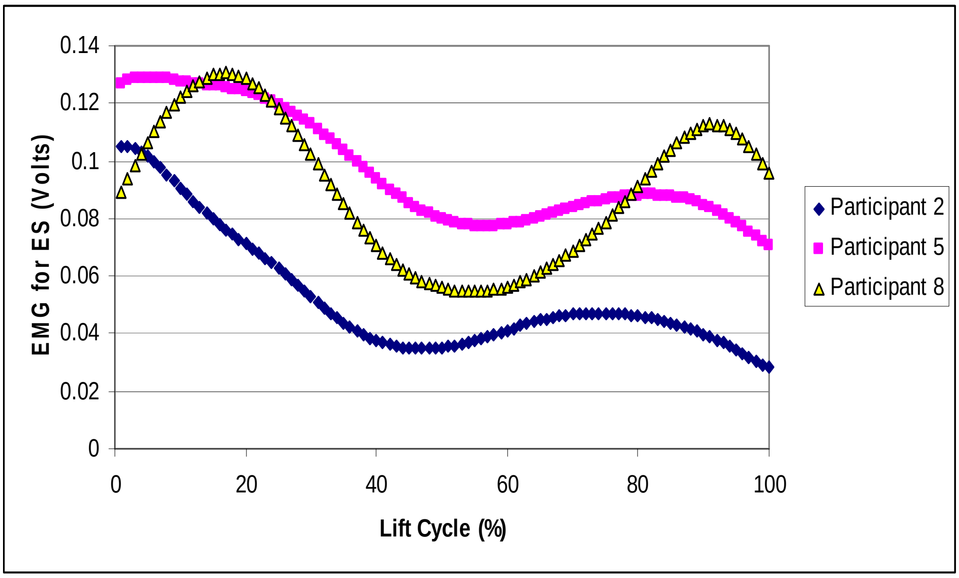


Figure 37 EMG curve for Erector Spinae Muscles during a Forward, Medium Duration Lift with No LAD

CHAPTER 4

DISCUSSION

The purpose of this study was to investigate the effectiveness of various LAD designs, and identify key features to be incorporated into future LAD designs. This was done by investigating lifting patterns and muscle activity with the use of different LADs under various lifting conditions. These lifting patterns were compared to lifting patterns observed with no device.

EMG Data

Figure 12 through Figure 15 show the mean right Erector Spinae muscle activity compared to LADs under varying lifting conditions, and may be observed to show some interesting effects of specific LADs. For example, Figure 12 and Figure 13 (MRES for all lifts, and MRES for forward lifts, respectively) show that using the Springzback device causes nearly the same Erector Spinae activity as when no device is worn. However, for lifting to the left, the MRES activity was increased, while it was conversely decreased when lifting to the right. For this parameter, the Bending device appears to be most severe for the MRES activity for forward lifts, and decreases the MRES activity substantially when lifting to the left or right. Furthermore, the Torsion Spring device reduced MRES activity for every kind of lift. These observations are confirmed in the similar findings from the PRES and CRES analyses. The only case for which this is not true is shown in Figure 16 and Table 7 where the Springzback device has a slightly lower value than the value with no device.

It was suspected that the added torque from a LAD may increase activity in the Rectus Abdominus muscles. In some cases, this was found to be true. The effect of the LAD on the rectus abdominus muscles may be observed in Figure 18 and Table 8 where the Torsion Spring device is shown to be different from the other LADs causing an increase in right rectus abdominus activity. The effects may be further observed in Figure 19 and Table 10 where the Springzback device was found to increase the peak muscle activity, which was also true for the mean and cumulative activity values.

Although the analyses for the external oblique muscle activity did not show a statistically significant pattern between LADs as was observed with other muscles, an interesting observation was made. Figure 20 and Table 11, along with Figure 21 and Table 12, show that the contralateral muscle is activated for a twisting action as may be expected, but the activity level for a forward lift is even lower than the ipsilateral muscle during a twisting lift. It may be that the ipsilateral muscle is cocontracting to provide some stabilization during a twisting lift where stabilization can be provided more efficiently by the more medial abdominal muscles during a forward lift. It may also be possible that the electrodes for the external oblique muscles are also partially reading the EMG signal from the internal oblique muscles because of their relative proximity. Since the ipsilateral internal oblique muscle causes a similar twisting motion as the contralateral external oblique muscle, some muscle activity may be detectable on both sides of the abdomen during rotation.

Motion Capture Data

One of the interesting results from the statistical analysis revealed a difference in means (p=0.019) when the mean moment arm was compared between devices for forward lifts (power = 0.764). Since a greater moment arm is considered to cause greater strain on the back, it is interesting to note the order of devices from least severe to most severe: Bending Device (BD), No Device (ND), Springzback (SB), Torsion Spring (TS). Figure 22 displays this information as well as the overlapping of groups determined using Tukey's HSD post-hoc test. Table 13 shows the grouping as well as the mean for each group.

These results are noteworthy because an increased moment arm may suggest two things for the user: increased risk of stress to the lower back, and reduced resistance of movement. Although the Bending Device may provide the least ease of movement while lifting, it reduces the moment arm the most. It is also interesting to note that the Springzback and Bending Devices were grouped along with the No Device lifts. For this parameter (mean moment arm), the only difference between groups is between the Torsion Spring Device and the Bending Device.

Similar results were obtained for the Peak Moment Arm (PMA) parameter, as shown in Figure 23. However, statistical significance was not obtained between groups. Similar trending in means was found when comparing Table 14 and Table 13. For this parameter, the Torsion Spring Device appears to be associated with the highest PMA, while the Bending Device is associated with the lowest.

Another interesting result was found in the difference between devices for the Peak Torso Angle parameter (p=0.002) for forward lifts only (power = 0.920). Figure 24 shows that not using a device (ND) allows the user to stand the most upright, and that each LAD caused the user to bend over more than normal. As shown in Table 15, Tukey's HSD post-hoc test revealed that the Springzback Device is the only device in the same group as No Device. However, all three of the devices are shown to cause a difference in lifting technique in that the user maintains a more forward flexed posture.

For forward lifts, the mean angle of twist (MTW) showed significant differences between devices. Figure 25 shows the groups' data in relation to one another. Table 16 confirms that the Torsion Spring Device and Bending Device stand together in a group that is different from the group including Springzback and No Device. Table 16 also shows that for this parameter on a forward lift, the Springzback is almost identical to not wearing a LAD.

The cumulative angle of twist (CTW) during forward lifting showed similar differences between devices to that of MTW. Figure 26 shows the groups' data in relation to one another. Table 17 confirms similar groupings to those found in Table 16. This is important to note because it shows that this relationship holds true even for lifts of varying duration.

Survey Data

The second question on the questionnaire allowed the participants to give a rating of comfort for each device by simply asking, "Was the device comfortable?" Although a oneway ANOVA did not yield statistical significance ($p=0.1525$) for this question across devices, examination of descriptive statistics shown in Table 18 reveals that the greatest mean comfort level is attributed to the Springzback device.

Question seven is the negative of question 2. The question is, "Does the weight of the device cause discomfort?" This question allowed the participant to respond to the level of discomfort, as opposed to the level of comfort, except that it specifies the weight of the device as the cause of discomfort. The results for this question yielded similar findings to those from question 2. Although the oneway ANOVA did not yield statistical significance (p=0.496) for this question, examination of descriptive statistics shown in Table 19 reveals that the greatest mean discomfort level is attributed to the bending device (3.1), but is very close to the torsion spring device (3.0). Springzback (2.6) appears to cause the least discomfort.

Question one asked "Was the device easy to put on and take off?" Table 21 shows that the participants chose the Springzback device as the easiest to put on and take off with a mean score of 3.7. The bending device was placed in a similar group with both the other devices with a mean score of 2.7, while the Torsions Spring device was ranked the hardest to put on and take off at a mean score of 2.4.

Questions three asked "Does the device adjust to fit you well?" Table 23 displays the Springzback device received the highest mean score at 3.2. The Torsion Spring device placed in both groups with a mean score of 3.0, while the Bending Device had the most negative mean score at 2.1.

Question nine reads "Does the device look appealing?" Although the oneway ANOVA was not statistically significant (p=0.084), Figure 31 showed that the Springzback device received the highest mean score, while the Bending device received the lowest.

The responses from questions one, three, and nine suggest that the design attributes used in the Springzback device allow for the greatest ease to put on and take off the device, the greatest adjustability for a good fit, and the greatest appeal in appearance. This design also received the highest comfort mean score and lowest discomfort due to weight mean score. Thus, in each of the above described categories of the survey, the Springzback design received the most positive feedback from the participants.

Subjective Responses from the Survey

The subjective responses in Table 25, Table 26, and Table 27 were generally similar across participants. According to the participants, the Bending device was too heavy, hard to put on and take off, and needs more padding. It was also considered too restrictive, and requires more adjustability. Some of these responses can be confirmed in the motion capture data. For example, Figure 22 shows that this device decreases mean moment arm, and Figure 24 shows that the bending device causes the user to deviate the furthest from a natural torso angle. However, considering the simplicity of the mechanism for generating torque, the user-suggested modifications for this design could be easily put into effect.

For the Springzback device, the participants indicated that the hard plastic interface was uncomfortable, and that it may be remedied with some padding. They further suggested that there were too many adjustments. While this device restricted movement the least, it also seemed to increase muscle activity, as shown in Figure 14 Figure 17, and Figure 19.

Additional Observations

An interesting finding can be drawn from observing the forward lift cycles with no device at the three different speeds. The torso angle chart shown in Figure 32 indicates that there was the least amount of overshoot with the fast lift, and the peak torso angle occurred about 10% later in the cycle. The slow and medium lifts show that the major changes in torso angle were complete at about 60% of the cycle, with the remainder of the lifting cycle dedicated to extending the load out to the target destination. However, the fast lift shows changes in angle occurred later on in the cycle (earlier in seconds). This may suggest that the most comfortable lifting speed is somewhere between the medium and fast lifting durations: between 2 seconds and 1 second. This converts to an overall load speed between 15 and 30 inches per second.

Furthermore, a similar observation of the moment arm distance in Figure 33 shows that peaks occur at similar points in the cycle, showing that the part of the cycle with the greatest torso angle is where the moment arm is the greatest, bearing in mind that as torso angle is increased, compression on the back should decrease. Again, the overshoot is greatest with the slow lift, but the overshoot moment arm for medium and fast lifts appear similar.

When these patterns are compared to the same lifting scenario with a lifting device, an interesting phenomenon is observed. There appears to be much less variability in Torso Angle across the three speeds in Figure 34, which shows one of the effects of the Torsion Spring LAD. This may be due to the restriction imposed by the device that effect motion and speed. In contrast, however, a great deal of variability is observed in the moment arm, as shown in Figure 35. This may indicate that since the torso angle is restricted to a specific lifting pattern, the arms take on more variability in motion to reach the load and to place the object at the target destination. This would be a reasonable explanation for the variability in moment arm at different speeds.

Another observation was made in the twisting motion of the lifts, as displayed in Figure 36, which is taken from the trials from one participant. The greatest angular deviation from neutral was observed with the Springzback, which appears to allow its user to twist with similar motion to the no device lifting scenario. This may suggest that the Springzback device is less restrictive for twisting motion. Although the Bending Device and the Torsion Spring Device seem to maintain greater torsional rigidity between the upper and lower body, which may be better for the user's back, the Springzback allows greater freedom of motion, which may increase its appeal to the user. This identifies both positive and negative effects of including the special joints that are unique to the Springzback Device.

Finally, an interesting observation was made in the EMG recordings of the Erector Spinae muscles for a medium speed, forward lift with no device. To initiate a lift, the signal increased, and then rapidly declined as the torso rose at a relatively constant rate. This is shown in Figure 37, and although there is a general similarity in the features of the curve, there is a pattern to the variability in the magnitude of those features. The peaks and valley associated with participant 8 appear to be much more accentuated than those associated with participants 2 and 5. This observation may be useful in future studies to recognize a lift based on the EMG reading of the erector spinae muscles.

CHAPTER 5

CONCLUSION

The goal of this study was to investigate the effect of LADs on lifting posture and trunk muscle activation under different lifting scenarios. This study was also intended to discover which designs reduce the risk of causing LBP associated with lifting, and in what way. This was done by measuring parameters which are known to be associated with this risk (i.e., moment arm, torso angle, etc.), under varying lifting situations, as well as other parameters which may be associated with the risk of causing LBP.

Lifting techniques were observed and relationships were identified with specific devices, allowing for recommendations about particular design characteristics to be used for future LAD designs. It was observed that the muscle activity was generally increased when using the Springzback device, but this was also the device that received the most positive responses from the survey. The Springzback altered lifting posture the least when compared to using no device. The Bending device generally decreased muscle activity, but caused a significant change in lifting posture, and received the most negative responses from the survey. It was also the device participants most frequently chose not to use. The Torsion Spring device was found to increase parameters such as moment arm and torso angle and rectus abdominus activity, but it also reduced erector spinae activity and generally scored positively along with the Springzback device on the survey. To illustrate some of the effects of each LAD, the mean of all the cumulative values for forward, left, and right lifts were calculated as a percentage of the parameter value for no device. The cumulative values were used because spinal loading has more recently been studied using this method [8]. Table 28 shows the percentages for forward lifts, while Table 29 and Table 30 show percentages for left and right lifts, respectively. Significant differences between LADs are indicated by superscript letters for pair-wise differences, and bold fonts.

Table 28 Mean of cumulative parameter values as a percentage of No Device values – Forward lifts only

Forward Lifts			
Parameter	Springzback	Bending Device	Torsion Spring
CTA	105.8	89.6	97.4
CLHA	104.8	96.1	97.7
CRHA	103.8	101.2	101.5
CTW	**88.5** $^{t\,b}$	**-204.3** $^{n\,s}$	**-372.1** $^{n\,s}$
CSE	149.4	-37.7	39.6
CMA	109.2	100.0	111.9
CRES	96.0	164.2	74.3
CRRA	132.5	83.1	115.6
CREO	102.6	90.0	97.8
CLES	114.3	90.6	107.1
CLRA	75.8	77.7	108.8
CLEO	105.4	84.9	98.3
Statistically significant differences between groups are indicated: n = No Device s = Springzback b = Bending device t = Torsion spring			

Table 29 Mean of cumulative parameter values as a percentage of No Device values – Left lifts only

Left Lifts			
Parameter	Springzback	Bending Device	Torsion Spring
CTA	97.3	83.3	93.5
CLHA	97.1	98.6	92.5
CRHA	94.7	95.9	93.2
CTW	103.5	99.8	94.6
CSE	**269.5** ^{t}	176.4	**12** ^{s}
CMA	96.9	104.9	96.2
CRES	133	71	55.2
CRRA	133.8	82.4	74.2
CREO	101.4	130	88.7
CLES	78.2	44.3	71.2
CLRA	69.7	86.7	102.5
CLEO	90.3	47.9	80.1
Statistically significant differences between groups are indicated: n = No Device s = Springzback b = Bending device t = Torsion spring			

Table 30 Mean of cumulative parameter values as a percentage of No Device values – Right lifts only

Right Lifts			
Parameter	Springzback	Bending Device	Torsion Spring
CTA	100.8	78.7	103.7
CLHA	99.8	89.5	101.3
CRHA	100	94.5	108.6
CTW	101.6 [t]	38.8	7.2 [n s]
CSE	206.7 [b t]	-12.1 [s]	31 [s]
CMA	105.5	101.7	110.3
CRES	74.2	56.5	46.9
CRRA	79.8	58.3	86.1
CREO	85.4	102.6	87.8
CLES	91.6	69.7	113.9
CLRA	99.4	80.7	82.2
CLEO	91.6	90.8	68.6
Statistically significant differences between groups are indicated: n = No Device s = Springzback b = Bending device t = Torsion spring			

The Tables 28 through 30 allow for easy comparison of the effect of the LADs between devices and parameters. When considering these findings in conjunction with the survey data, many differences as well as similarities between devices were identified. Furthermore, the strengths and weaknesses of each device were identified. For example, the Springzback device did not reduce erector spinae activity, but allowed the most natural movement. However, the Torsion Spring device provided the opposite effect: reducing erector spinae activity while restricting natural movement. Therefore, the Springzback device may be ideal for a situation in which motion is necessary, where the Torsion Spring device would be better suited to jobs requiring a static bent posture.

APPENDIX

BODY MASS INDEX (BMI)

Body Mass Index (BMI) is a number calculated from a person's weight and height. BMI is a reliable indicator of body fatness for humans, and can be considered an alternative for direct measures of body fat. Additionally, BMI is an inexpensive and easy-to-perform method of screening for weight categories that may lead to health problems.

BMI Calculation Formula

Unit	**Formula**
Kilograms & meters	weight (kg) / [height (m)]^2
Pounds & inches	weight (lb) / [height (in)]^2 x 703

BMI Interpretation

BMI	**Weight Status**
Below 18.5	Underweight
18.5 – 24.9	Normal
25.0 – 29.9	Overweight
30.0 and Above	Obese

Questionnaire

	Strongly Disagree	Disagree	Neither Agree nor Disagre	Agree	Strongly Agree
Was the device easy to put on and take off?					
Was the device comfortable?					
Does the device adjust to fit you well?					
Were you able to effectively use and control this device as you believe it is intended to be used and controlled?					
Does the device reduce stress in the back while lifting?					
Was the weight of the device a problem for the lifting tasks?					
Does the weight of the device cause discomfort?					
Would you be willing to wear the device for 8 working hours in a day?					
Does the device look appealing?					

If given more time and practice using the device, would it become more useful to you? (circle one) YES NO

What is the hardest or worst part about using this device?

If you could change one thing about this device, what would it be?

What aspects of the device seem awkward, uncomfortable, unsafe, or more difficult than necessary?

If given the right opportunity or necessity, would you want to use the device? (circle one) YES NO

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